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VALIDATION OF **WAVELOAD** VERSION 1.0 FOR THE CASE OF A DESTROYER IN REGULAR HEAD WAVES

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Centre for Marine Vessel Development and Research

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ABSTRACT

The prediction of ship motions, sea loads and hydrodynamic pressure distribution over a ship hull is an essential component of ship structural design. The immediate goal is to provide accurate hull pressure input for the finite-element structural analysis. To this end, the computer program *WAVELOAD* version 1.0 has been developed to predict ship motions, wave loads, and hydrodynamic pressure in the frequency domain based on the three-dimensional panel method.

This report describes the experimental validation of this program using the data from experimental tests with a destroyer model in head seas. The total factor error (TFE) was used as an index of correlation of predicted and measured transfer functions. By examining TFE values, one can assess not only the degree of correlation between predicted and measured response transfer functions quantitatively, but also the reliability of the experimental data. The TFE analysis was applied to the predictions by two other computer programs, *PRECAL* and *SHIPMO7*, as well as to those by *WAVELOAD*. The results show that *WAVELOAD* is a reliable software package for sea-load predictions.

RÉSUMÉ

La prédiction des mouvements des navires , les charges de mer et la répartition des pressions hydrodynamiques sur la coque est une composante essentielle de la conception de la structure du navire. Le but immédiat est de fournir des données précises sur les pressions qui s'exercent sur la coque pour l'analyse de la structure par la méthode des éléments finis. Le programme informatique *WAVELOAD,* version 1.0, a été développé à cette fin pour prédire les mouvements des navires, les charges des vagues et la pression hydrodynamique dans le domaine des fréquences basé sur la méthode des panneaux en trois dimensions.

Ce rapport décrit la validation de ce programme à l'aide de données d'essais expérimentaux effectuées sur un modèle de destroyer avec une houle de l'avant . On a utilisé l'erreur totale des facteurs (TFE) comme indice de corrélation des fonctions de transfert prédites et mesurées. En examinant les valeurs TFE, on peut évaluer quantitativement le degré de corrélation entre les fonctions de transfert de réponse prédites et mesurées, mais aussi la fiabilité des données expérimentales. L'analyse TFE a été appliquée aux prédictions données par deux autres programmes informatiques, *PRECAL* et *SHIPMO7*, ainsi qu'à celles faites par *WAVELOAD*. Les résultats montrent que est un progiciel fiable pour la prédiction des charges de mer.

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1. INTRODUCTION

The prediction of ship motions, sea loads and hydrodynamic pressure distributions over a ship hull is an essential component of ship design. An important use of such data is to provide accurate inputs for the finite-element structural analysis of ship hulls. To this end, a computer program package, ***WAVELOAD*** version 1.0 [1], was developed at the Center for Marine Vessel Development and Research (CMVDR). Based on the three-dimensional panel-method, ***WAVELOAD*** is developed to predict ship motions, sea loads and hydrodynamic pressures over a ship hull in the frequency domain.

As a basic aspect of code development, experimental validation of the program was carried out to assess the predicted motions and hydrodynamic pressures over the hull of a destroyer in regular head waves. Furthermore, to overcome the shortcomings of conventional method of code validation, which is based on the visual evaluation of the data and is apt to be inconsistent and inefficient, the total factor error [2] (TFE) was used as an index of correlation between the predicted and measured transfer functions. By examining TFE values, one can assess the degree of correlation between predicted and measured transfer function quantitatively, as well as the reliability of the experimental data. The TFE analysis was also applied to the predictions of two other computer programs, ***PRECAL*** [3] and ***SHIPMO7*** [4], as well as to those by ***WAVELOAD***. ***PRECAL*** is also a three-dimensional panel-method code in the frequency domain, developed by the Maritime Research Institute (MARIN), the Netherlands. ***SHIPMO7*** is a strip-theory code developed by the Defence Research Establishment Atlantic (DREA) for ship motions and wave loads. It cannot predict hydrodynamic pressure distributions on the hull.

The results described in this report demonstrate that ***WAVELOAD*** is a reliable software package for predicting ship motions and sea loads.

2. EXPERIMENTAL DATA

The test data are from the model tests of the DDH-280 destroyer [5]. The model tests were conducted at the Institute for Marine Dynamics (IMD), St. John's, Newfoundland. The data were obtained by using a self-propelled 9-m model (Model 391, 1/13.48-scale), which was advancing in regular head waves of $0.25 \le \lambda/L \le 1.5$ at Froude numbers $Fn = 0.0$, 0.1, 0.2, 0.29, 0.37 and 0.39. In this report, λ/L denotes the wave-length to ship-length ratio. The model was free to pitch and heave, but constrained in other modes. The limit of $\lambda/L \le 1.5$ was set in order not to exceed the commonly-used deep-water criterion, i.e., $h/\lambda > 1/2$, where h is the depth of the tank (7m). In the experiment, the model was run twice at a prescribed wave frequency at all Froude numbers except Fn=0.10 as a check on repeatability. As it can be seen, from the coincidence of two data points at each wave frequency for a given Froude number in the figures below, repeatability of the runs was excellent; the only exception was for $\lambda/L = 0.25$, where differences between the two points are sometimes evident.

Table 1 gives the particulars of the ship and the model. Table 2 gives the beam, draft, and sectional area of each station along the length of the hull. Locations of pressure transducers are given in Table 3. Figures 1 and 2 show the lines drawing of Model 391 and the positions of pressure transducers. The model was equipped with a rudder, shafts, and A-brackets, but no other appendages.

3. THE TOTAL FACTOR ERROR ANALYSIS

As described in the reference [2], the correlation of predicted and measured transfer functions for ship motions and wave loads can be validated by the total factor error (TFE) to eliminate the visual evaluation and qualitative judgement of the experimental validation. TFE provides an efficient, as well as objective, means of evaluating the reliability of the computer-predicted transfer functions for ship responses.

Under the assumption of a linear relationship between ocean waves and the ship's response, the power spectral density (PSD) functions are related by:

$$S_{resp}(\omega) = |H(\omega)|^2 S(\omega) \qquad (1)$$

where $S(\omega)$ and $S_{resp}(\omega)$ are the PSD's of the wave and the ship's response, respectively, and $H(\omega)$ is the transfer function for the ship's response. The absolute value of the transfer function, $|H(\omega)|^2$, is often called the response amplitude operator (RAO). The wave spectral density, $S(\omega)$, can be either a mathematical model (the Pierson-Moskowitz, ITTC, JONSWAP, Ochi-Hubble, etc.) or an actual ocean spectrum.

As the first step in defining the total factor error, the following expression is useful:

$$\int \{|\hat{H}(\omega)| - |H(\omega)|\}^2 S(\omega) d\omega, \qquad (2)$$

where $\hat{H}(\omega)$ is the predicted value of the transfer function and $H(\omega)$ is the experimental value. The expression (2) may be regarded as the mean square error (MSE) of the predicted transfer function relative to the wave spectrum $S(\omega)$. It gives the weighted deviation between prediction and experiment. The amount of difference is weighted by a measure of its importance in terms of the harmonic content of the wave spectrum $S(\omega)$.

For a prescribed wave spectrum and a particular set of experimental data, the values of (2) can be used to rate the relative merits of two or more sets of predictions. Since the area under the power spectrum is an important parameter in the spectral analysis, the ratio of the MSE to the area under the reference response spectrum,

$$\frac{\int \{|\hat{H}(\omega)| - |H(\omega)|\}^2 S(\omega) d\omega}{\int |H(\omega)|^2 S(\omega) d\omega} \qquad (3)$$

provides a more meaningful measurement of importance to the error associated with the predicted transfer function. In (3), ω ranges from 0 to infinity, however the experimental values of ω are bounded due to physical constraints: its lowest value is usually limited by the water depth of the tank and the highest is limited by the power of the wavemaker. Moreover, only a finite set of discrete values of the measured transfer functions, $\{H(\omega_i)\}$ for $\omega \in \{\omega_i\}, i = 1,2,...,N$, is available in practice. We therefore define the total factor error by the square root ε of the following expression,

$$\varepsilon^2 = \frac{\sum_{i=1}^{N} \{|\hat{H}(\omega_i)| - |H(\omega_i)|\}^2 S(\omega_i)}{\sum_{i=1}^{N} |H(\omega_i)|^2 S(\omega_i)} \qquad (4)$$

as a measurement of error of the predicted transfer function. Since ε is usually a small number, it is convenient to multiply it by 100 and express TFE as percentage. Obviously, the value of ε is relative to a particular data set, i.e., it depends on the number and the composition of data points.

In the TFE calculations, ITTC and JONSWAP wave spectra were used. The corresponding parameters are shown in Table 4. The TFE's of heave and pitch transfer functions and pressures at 16 transducer locations for six different forward speeds were calculated based on the test data points and wave spectra. Note that there are 10, 7, 10, 12, 13 and 12 measured transfer functions at Fn=0.0, 0.1, 0.2, 0.29, 0.37 and 0.39, respectively.

4. CONVERGENCE TESTS

To increase the accuracy of predicted heave and pitch motions and hydrodynamic pressures, it is desirable to use as many panels as possible. In the present study, nine geometric models, with 100, 150, 200, 250, 300, 350, 400, 450 and 500 panels on the port side of the wetted hull surface, were examined for ***WAVELOAD***. In these geometric models, the nominal aspect ratios of panels were kept close to one. All of these models are shown in Figure 3. Note that panels on the stern can be identified through Figure 3(b).

Tables 5 and 6 give the TFE's of predicted heave and pitch motions with nine geometric models at $Fn = 0.0,\ 0.1, 0.2, 0.29, 0.37$ and 0.39 for ITTC Sea State 4. The TFE's show that the predicted heave and pitch transfer functions are basically independent on the number of panels, except for pitch predictions at $Fn = 0.37$ and 0.39. In Figure 4, the TFE's of the predicted pressures at 16 transducer locations are also plotted against the number of panels. However, it appears that merely increasing the number of panels in a geometric model does not necessarily lead to more accurate predictions of hydrodynamic pressures. At lower speeds, say, $Fn = 0.0,\ 0.1$ and 0.2, the predicted pressures on all transducer locations do not change with increasing the number of panels. At higher speeds, the predicted pressures at some transducers on the aft body tended to converge to those in the experimental data. However, we cannot use finer panels without a penalty. In fact, "too many" panels tended to increase the computing time.

As a compromise, the geometry model with 150 panels was chosen for the computation.

5. RESULT OF CALCULATIONS

For the purpose of the validation study, ***WAVELOAD***'s predictions were checked at the experimental frequencies. The correlation with experimental results was represented by the total factor errors. Furthermore, the predictions were checked at 60 wavelengths between $0.025 \le \lambda / L \le 2.0$. In these studies, the predictions of ***WAVELOAD*** were also compared with those from ***PRECAL*** and ***SHIPMO7***.

5.1 Ship Motions

In figure 5, plots of predicted heave and pitch motion amplitudes and the phase angles are shown. The plots were generated with the calculated responses at *Fn*=0.0, 0.1, 0.2, 0.29, 0.37 and 0.39. Amplitudes of the heave- and pitch-motion transfer functions were nondimensionalized by dividing them respectively by the amplitude a of the incident wave and the wave slope $k_0 a$, where $k_0 = \omega_0^2 / g$ is the wavenumber, ω_0 is the incident wave frequency, and g is the gravitational acceleration. In these plots, the predicted motions from ***WAVELOAD*** were compared with experimental results, as well as predictions from ***PRECAL*** and ***SHIPMO7***.

The predicted pitch transfer functions and phase angles from ***WAVELOAD*** agree well with test data for all speeds. At higher speeds, ***WAVELOAD*** tends to predict pitch motions more accurately than ***PRECAL*** and ***SHIPMO7***. However, ***WAVELOAD*** overestimated heave motions at higher speeds when $\lambda / L > 1.0$. Irregular frequencies affected predictions when λ / L was of the order of 0.5.

To quantitatively compare ***WAVELOAD*** predictions with those of ***PRECAL*** and ***SHIPMO7***, the TFE analyses were applied to the three programs. TFE's of predicted heave and pitch motions from three programs are listed in Tables 7 through 9 for ITTC and JONSWAP spectra at six different forward speeds. At zero speed, ***WAVELOAD*** has similar performance to ***PRECAL*** and ***SHIPMO7***. At *Fn*=0.29, 0.37 and 0.39, the ***WAVELOAD*** pitch TFE is approximately half the value from ***PRECAL*** and ***SHIPMO7***. However, at *Fn*=0.2, it is worse than the other two for pitch prediction. When *Fn*>0.1, ***WAVELOAD*** has bigger TFE's of heave predictions than the other two. It is also interesting that ***SHIPMO7*** can predict heave motions better than ***WAVELOAD*** and ***PRECAL*** at all speeds except *Fn*=0.0.

5.2 Hydrodynamic Pressure on the Wetted Hull Surface

Figures 6 through 11 show the plots of predicted hydrodynamic pressures at 16 transducer locations for six speeds. The pressures were nondimensionalized by dividing

them by ρga, where ρ is the density of water. Note that the measured pressures and phase angles are not available on transducer 6 at Fn=0.29. Therefore the measured pressures and their phases are zero in Figure 9 (f). The predicted pressures and phases from ***PRECAL*** are also plotted in these figures. At zero speed, the predictions of ***WAVELOAD*** agree well with measured data on all 16 transducer locations. With forward speed increased, both ***WAVELOAD*** and ***PRECAL*** tended to overestimate pressures around the bow region when $\lambda/L > 1.0$. At higher speed, the bow may lift off the water so that the sensors on the bow might not measure pressures accurately. At *Fn*=0.37 and 0.39, these two programs predicted pressures better on the midship region than the other parts of the hull. This may be caused by hull impacts at the bow and stern. In this case, the linear theory might not be applicable. Again, irregular frequencies occurred on all transducer locations when $\lambda/L < 0.6$ at *Fn*=0.0, 0.1 and 0.2, and as speed increased they appeared on the region of $\lambda/L < 1.0$.

Color plots of pressure distributions over the hull surface are given in Figures 12 –17 for six speeds and six wavelength ratios ($\lambda/L = 0.25$, 0.5, 0.75, 1.0, 1.25 and 1.5). Figure 18 shows the relationship between the non-dimensional maximum pressure over the hull panels and the wavelength ratio at six speeds. In these figures, *x*, *y*, and *z* represent coordinates of the location of maximum pressure over the hull. At zero speed, the maximum pressures were encountered in the bow region. As shown in Figure 18(a), the maximum pressure increased with the wavelength ratio and decreased when $\lambda/L > 1.0$. At *Fn*=0.1, 0.2 and 0.29, the location of maximum pressure moved from the stern region to the bow region as the wavelength ratio increased. When $\lambda/L > 1.0$, the maximum pressures are almost two times higher than those at $\lambda/L < 1.0$ for *Fn*=0.29, 0.37 and 0.39. At *Fn*=0.37, the location of maximum pressure moved from the stern to ¼ bow region, then ¼ stern region and stayed in the bow region when $\lambda/L > 1.0$. At *Fn*=0.39, the location of maximum pressure shifted from stern to bow as the wavelength ratio increased.

Figure 19 shows the relationship between the maximum pressure and the forward speed for six wavelength ratios. At long waves ($\lambda/L = 1.0$, 1.25 and 1.5), the location of

maximum pressure stayed at the bow region for all speeds. At $\lambda/L=0.25$, it shifted from bow to stern and then ¼ stern region with increasing speed. At $\lambda/L=0.50$, it moved from bow region to midship, then stern, ¼ bow region and to ¼ stern region. At $\lambda/L=0.75$, it shifted from bow to midship. It is also found that at $\lambda/L=0.75$ and 1.5, the value of maximum pressure kept increasing with the forward speed.

Tables 10 through 21 show the total factor errors of predicted hydrodynamic pressures at 16 transducer locations for six forward speeds. TFE's are based on ITTC and JONSWAP wave spectra and available test data. The TFE's are also compared with those from ***PRECAL***. TFE's from ***SHIPMO7*** are not available since this program cannot predict hydrodynamic pressures. The TFE's of pressures at 16 transducer locations for 6 speeds are also plotted in Figure 20. Note that in these figures symbols ◊ and + represent the TFE's of ***WAVELOAD*** and ***PRECAL***, respectively. At zero speed, ***WAVELOAD*** predicted pressures slightly better than ***PRECAL*** on most transducer locations. However, both programs had worse predictions on locations of transducers 6 and 14 for all sea states compared to other locations. For the JONSWAP wave spectrum, the predictions on these two locations were even worse.

At *Fn*=0.1, ***PRECAL*** predicted pressures slightly better than ***WAVELOAD*** at most transducer locations. At *Fn*=0.2, ***WAVELOAD*** provided better predictions on the midship transducer locations than ***PRECAL***. At *Fn*=0.29, both programs had bigger TFE values on the location of transducer 6. It indicated that the measured data in this case might not be reasonable. At *Fn*=0.37 and 0.39, TFE values at locations of transducers 14, 15, and 16 seemed unreasonable for all sea states. Again, this may has been caused by the stern impact. At higher speeds, both programs have similar predictions on all transducer locations except 14, 15, and 16.

6. CONCLUDING REMARKS

This validation study of ***WAVELOAD*** program has focused on a destroyer hull. The validation was carried out by checking the predictions of ship motions and hydrodynamic pressures on the hull in regular head waves against model test data. The predictions from ***WAVELOAD*** were also compared with those from the ***PRECAL*** and ***SHIPMO7*** programs using both TFE analysis and visual judgement. The following concluding remarks were reached for ***WAVELOAD*** version 1.0 validation:

- ***WAVELOAD*** version 1.0 is a reliable computer program for the predictions of ship motions and hydrodynamic pressure distributions over the ship hull.
- Predicted and measured pitch motions agree well for all Froude numbers.
- The panel-method is sensitive to the geometry model for the prediction of pressure distribution at higher speeds. The geometry model with finer panels does not necessarily lead to more accurate predictions of hydrodynamic pressures.
- Total factor error (TFE) provides a quantitative index to assess the predictions from different programs. These TFE analyses show that ***WAVELOAD*** version 1.0 is a competitive program for predicting pitch and pressures. However, the TFE's for heave show poor correlation with measured data at $Fn \neq 0$.
- Such TFE analyses can also be used to check the reliability of the experimental data as well. As a result, some experimental pressure data were found questionable.
- Ideally, with more test data the TFE analysis will be more reliable. The current TFE analyses were therefore limited by the amount of test data available.
- The current conclusions are based on the validation studies of a destroyer in head seas. For a more thorough validation, oblique waves should also be considered, and these should be applied to the ***PRECAL*** and ***SHIPMO7*** programs.

7. RECOMMENDATIONS

As part of the development of new ***WAVELOAD*** versions, the following are some of the points raised in the correlation studies that should be addressed in the future work.

- In version 1.0, the zero speed Green's function with the simplified m-terms effect was used. A better correlation between the predicted and measured hull pressures could be achieved by the improved m-terms.
- TFE tables showed that ***WAVELOAD*** version 1.0 provided worse heave predictions than ***PRECAL*** and ***SHIPMO7*** at higher speeds. An effort should be made to improve predictions under these conditions.
- A study should be carried out to find the relation between the pressure prediction and the geometry of the hull model. In a long term development or research project, an adaptive hull discretization approach should be considered to provide users with an optimum hull geometry model.
- Further validation studies should include oblique waves and other type of ships, if data are available.

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TABLES

Table 1 Particulars of ship and model (NRC/IMD model 391)

Designation	Ship	Model
Scale ratio	1	1/13.479
Length between perpendiculars (L_{PP}, L)	121.31 m	900.0 cm
Length on waterline (L_{WL})	121.69 m	902.8 cm
Breadth at waterline at amidships (B)	15.20 m	112.8 cm
Breadth at waterline at maximum section	15.22 m	112.9 cm
Draft at forward perpendicular	4.73 m	35.1 cm
Draft at amidships (T)	4.73 m	35.1 cm
Draft at aft perpendicular	4.73 m	35.1 cm
Maximum section aft of amidships	6.07 m	45.0 cm
Parallel middle body, from aft of amidships	6.07 m	45.0 cm
to forward of amidships	-6.07 m	-45.0 cm
Area of midship station	60.14 m^2	0.3310 m^2
Area of maximum station	60.50 m^2	0.3330 m^2
Length/Beam ratio (L/B)	7.98	7.98
Beam/Draft ratio (B/T)	3.21	3.21
Centre of buoyancy aft of amidships (LCB)	3.23 m	24.0 cm
Centre of buoyancy of aftbody aft of amidships	22.57 m	167.5 cm
Centre of buoyancy of forebody forward of amidships	20.12 m	149.3 cm
Centre of buoyancy above baseline	2.86 m	21.2 cm
Volume of displacement (∇)	4552.52 m^3	1.859 m^3
Wetted surface area	1969.81 m^2	10.842 m^2
Volumetric coefficient (∇/L^3)	0.0025	0.0025
Block coefficient (∇/LBT)	0.520	0.520
Displacement (Δ)	4670.4 tonnes*	1859.0 kg**
Centre of flotation aft of amidships (LCF)	7.91 m	58.7cm
Centre of flotation of aftbody; aft of amidships	28.45 m	211.1 cm
Centre of flotation of forebody; forward of amidships	21.71 m	161.1 cm
Area of waterline plane	1419.31 m^2	7.812 m^2
Transverse metacentric radius (BM)	4.70 m	34.9 cm
Longitudinal metacentric radius (BM_L)	269.74 m	2001.2 cm
Area of profile plane	501.81 m^2	2.762 m^2
Centre of area of profile plane forward of amidships	5.07 m	37.6 cm
Centre of area of profile plane above baseline	2.48 m	18.4 cm

* Salt water

** Fresh water

Table 2 Sectional hull form at DWL

Sta	Beam $(B_x)^a$	Draft $(T_x)^b$	Area $(\sigma_x)^c$	$(A_x)^d$
0 (AP)	0.576	0.070	0.820	0.037
1	0.720	0.210	0.854	0.154
2	0.808	0.370	0.828	0.294
3	0.868	0.650	0.705	0.473
4	0.916	1.000	0.612	0.667
5	0.952	1.000	0.694	0.786
6	0.980	1.000	0.763	0.889
7	0.992	1.000	0.806	0.951
8	1.000	1.000	0.828	0.985
9	1.000	1.000	0.841	1.000
10	1.000	1.000	0.836	0.994
11	0.988	1.000	0.824	0.968
12	0.960	1.000	0.806	0.920
13	0.900	1.000	0.776	0.830
14	0.808	1.000	0.747	0.718
15	0.692	1.000	0.717	0.590
16	0.560	1.000	0.681	0.453
17	0.416	1.000	0.646	0.320
18	0.273	1.000	0.603	0.196
19	0.141	0.940	0.516	0.081
20 (FP)	0.000	0.000	0.000	0.000

[a] B_x = (Station Beam) / (Maximum Beam).
[b] T_x = (Station Draft) / (Maximum Draft).
[c] σ_x = (Station Area)/(Station Beam × Station Draft).
[d] A_x = (Station Area)/(Maximum Area).

Table 3 Locations of pressure sensors

Transducer No.	#Station	x (m)	y(m)	z(m)	Port/Starboard/Center
1	17	42.455	0	-4.73	C
2	17	42.455	-2.286	-2.18	S
3	16	36.39	-3.2004	-2.3	S
4	15	30.325	0	-4.73	C
5	15	30.325	-4.2672	-2.43	S
6	13	18.195	0	-4.73	C
7	13	18.195	-4.2672	-3.71	S
8	10	0	0	-4.73	C
9	10	0	-2.4384	-4.35	S
10	10	0	-6.096	-3.45	S
11	7	-18.195	0	-4.73	C
12	7	-18.195	4.2672	-3.84	P
13	7	-18.195	6.096	-3.2	P
14	5	-30.325	0	-4.73	C
15	5	-30.325	6.096	-2.43	P
16	3	-42.455	0	-3.068	P

Table 4 Wave spectra

Sea State	Hs (m)	Tp (sec)	Wave Spectra
4	1.88	8.8	ITTC
5	3.26	9.7	ITTC, JONSWAP
6	5	12.4	ITTC, JONSWAP
7	7.5	15	ITTC

Table 5 TFE's of predicted heave motion for ITTC Sea State 4

Number of panels	Fn 0	0.1	0.2	0.29	0.37	0.39
100	13.9	48.7	40.4	48.4	42.9	40
150	14	48.6	40.4	48	41.5	40
200	14.1	48.7	40.7	48	41.8	40.1
250	14.2	48.7	40.7	48	42.1	40.2
300	14.1	48.7	40.6	47.8	41.4	39.8
350	14.2	48.7	40.7	47.8	41.4	39.8
400	14.2	48.7	40.6	47.7	41.1	39.6
450	14.2	48.7	40.6	47.6	41	39.6
500	14.3	48.7	40.4	47.5	40.9	39.5

Table 6 TFE's of predicted pitch motion for ITTC Sea State 4

Number of panels	Fn 0	0.1	0.2	0.29	0.37	0.39
100	8.7	12.2	7.6	7.6	7.4	9.3
150	8.7	12.2	7.7	4.6	5.4	6.9
200	8.8	12.1	7.9	4.5	5.2	6.2
250	8.8	12.1	8	4.6	5.6	5.5
300	8.8	12.1	7.9	4.5	4.8	5
350	8.8	12.1	8	4.6	4.8	4.7
400	8.8	12.1	8	4.6	4.5	4.4
450	8.8	12.1	8.1	4.6	4.3	4.3
500	8.8	12.1	8.1	4.6	4.2	4.3

Table 7 Total factor errors of motion predictions for WAVELOAD, PRECAL and SHIPMO7 based on experimental data of Ref. 5 and ITTC spectrum: Sea State 4 (Hs=1.88m, Tp=8.8s) and Sea State 5 (Hs=3.26m, Tp=9.7s)

Speed	Motions	ITTC					
		Sea State 4			Sea State 5		
		WAVELOAD	PRECAL	SHIPMO7	WAVELOAD	PRECAL	SHIPMO7
Fn=0.0	Heave	14	13.9	17.1	11.7	11.6	14.6
	Pitch	8.7	7.7	13.5	7.4	6.1	12.6
Fn=0.1	Heave	48.6	41.9	35.5	45.2	39.3	33.1
	Pitch	12.2	13.4	12.7	12.7	13.6	12.8
Fn=0.2	Heave	40.4	21.1	18.3	38.4	19.9	16.9
	Pitch	7.7	3.9	2.6	7.9	3.8	2.2
Fn=0.29	Heave	48	23.2	20.9	48.9	23.2	20.7
	Pitch	4.6	5.3	8.7	4.5	4.7	8.6
Fn=0.37	Heave	41.5	17.2	12.7	43.9	17.9	13.3
	Pitch	5.4	13.1	10.4	4.8	11.3	10.6
Fn=0.39	Heave	40	15.1	10.5	41.6	15.5	10.8
	Pitch	6.9	11.3	10.9	5.7	9.8	10.9

Table 8 Total factor errors of motion predictions for WAVELOAD, PRECAL and SHIPMO7 based on experimental data of Ref. 5 and ITTC spectrum: Sea State 6 (Hs=5.0m, Tp=12.4s) and Sea State 7 (Hs=7.5m, Tp=15.0s)

Speed	Motions	ITTC					
		Sea State 6			Sea State 7		
		WAVELOAD	PRECAL	SHIPMO7	WAVELOAD	PRECAL	SHIPMO7
Fn=0.0	Heave	9.3	9.2	12.2	8.7	8.6	11.6
	Pitch	6.2	4.7	11.6	5.9	4.3	11.3
Fn=0.1	Heave	40.5	35.4	29.8	38.9	34.2	28.7
	Pitch	13.5	13.8	13	13.8	13.8	13
Fn=0.2	Heave	35.8	18.5	15.3	35	18.1	14.8
	Pitch	8.3	3.7	1.8	8.4	3.7	1.6
Fn=0.29	Heave	49.8	23.3	20.5	50	23.3	20.4
	Pitch	4.4	3.9	8.5	4.5	3.6	8.4
Fn=0.37	Heave	46.7	18.7	14.2	47.5	19	14.5
	Pitch	4.1	9.2	10.7	4	8.6	10.7
Fn=0.39	Heave	43.5	16	11.2	44.1	16.2	11.4
	Pitch	4.5	8.1	11	4.1	7.6	11

Table 9 Total factor errors of motion predictions for WAVELOAD, PRECAL and SHIPMO7 based on experimental data of Ref. 5 and JONSWAP spectrum: Sea State 5 (Hs=3.26m, Tp=9.7s) and Sea State 6 (Hs=5.0m, Tp=12.4s)

Speed	Motions	JONSWAP					
		Sea State 5			Sea State 6		
		WAVELOAD	PRECAL	SHIPMO7	WAVELOAD	PRECAL	SHIPMO7
Fn=0.0	Heave	8.9	8.8	11.8	8.5	8.4	11.3
	Pitch	6	4.5	11.4	5.8	4.2	11.2
Fn=0.1	Heave	39.5	34.7	29.2	38.3	33.7	28.3
	Pitch	13.7	13.8	13	13.9	13.9	13
Fn=0.2	Heave	35.3	18.2	15	34.7	17.9	14.6
	Pitch	8.3	3.7	1.7	8.4	3.7	1.8
Fn=0.29	Heave	49.9	23.3	20.4	50.1	23.3	20.4
	Pitch	4.5	3.7	8.4	4.5	3.5	8.3
Fn=0.37	Heave	47.2	18.9	14.4	47.8	19.1	14.6
	Pitch	4	8.9	10.7	3.9	8.4	10.7
Fn=0.39	Heave	43.9	16.1	11.3	44.3	16.2	11.4
	Pitch	4.3	7.8	11	4	7.4	11

Table 10 Total factor errors of pressures at Fn=0.0 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and ITTC spectrum: Sea States 4, 5, 6 and 7

Fn=0.0	ITTC							
	Sea State 4		Sea State 5		Sea State 6		Sea State 7	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	91.1	90.9	91.8	91.6	92.3	92.1	92.4	92.2
P-2	11.2	14.7	12	16	12.9	17.5	13.2	17.9
P-3	16.1	16.6	17.2	17.7	19	19.6	19.7	20.2
P-4	17.6	17.4	20.6	20	24.1	23.3	25	24.2
P-5	8.9	17	9.3	15.8	9.5	14.3	9.5	13.8
P-6	34.3	34.6	43.7	44.2	56.6	57.2	60.3	61.1
P-7	15.4	19.5	15.6	19.3	15.9	19	16	19
P-8	17.3	17.1	20.7	20.2	26.4	25.5	28.4	27.4
P-9	9.6	12.2	9	11.4	8	10.1	7.7	9.7
P-10	10.7	10.3	10.6	10.1	10.5	9.8	10.5	9.8
P-11	23.3	20.6	24.2	22	25.5	24	25.8	24.6
P-12	16.3	16.1	15.9	15.7	15.6	15.4	15.6	15.4
P-13	8.9	8.9	8.2	8.2	7.2	7.2	6.8	6.8
P-14	38.1	38.5	47	47.7	58.7	59.8	62	63.2
P-15	19.4	18.8	19.4	18.9	20.9	20.7	21.8	21.7
P-16	18.1	18.3	21.8	21.4	27.2	26.1	29	27.6

Table 11 Total factor errors of pressures at Fn=0.0 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and JONSWAP spectrum: Sea States 5 and 6

Fn=0.0	JONSWAP			
	Sea State 5		Sea State 6	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	92.4	92.2	92.4	92.2
P-2	13.1	17.8	13.3	18.1
P-3	19.4	20	19.9	20.5
P-4	24.7	23.8	25.4	24.5
P-5	9.5	14	9.5	13.6
P-6	58.9	59.6	61.8	62.6
P-7	16	19	16.1	18.9
P-8	27.6	26.6	29.3	28.2
P-9	7.8	9.9	7.5	9.5
P-10	10.4	9.8	10.5	9.8
P-11	25.7	24.4	26	24.9
P-12	15.6	15.4	15.6	15.4
P-13	6.9	7	6.6	6.7
P-14	60.7	61.9	63.3	64.5
P-15	21.4	21.3	22.1	22.2
P-16	28.3	27	29.7	28.2

Table 12 Total factor errors of pressures at Fn=0.1 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and ITTC spectrum: Sea States 4, 5, 6 and 7

Fn=0.1	ITTC							
	Sea State 4		Sea State 5		Sea State 6		Sea State 7	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	83.7	83.9	84.6	85	85.4	85.8	85.6	86
P-2	26.2	22.9	26.7	23.3	27.4	24	27.6	24.3
P-3	40.8	30.3	43	33.1	44.3	35.7	44.3	36.2
P-4	54.4	44.6	54.4	46	53.1	46.9	52.4	46.9
P-5	69.6	47.2	68.7	48.1	64.8	47.4	63	46.7
P-6	82.7	55.7	68.4	61.5	74.2	67.5	75.6	69.1
P-7	61.6	51.9	66	55.6	70.4	59.4	71.5	60.3
P-8	50.2	49.3	55.7	54.5	64.7	63	68	66.1
P-9	49.1	41.5	51.4	44.3	53.3	47.2	53.4	47.7
P-10	39.2	41.6	42.2	44.3	45.5	47.3	46.2	47.9
P-11	49.3	45.6	48.8	47.3	49.9	51	50.5	52.3
P-12	30.1	33.4	29.8	33.5	29.1	33.3	28.8	33.1
P-13	37.6	39.1	35.7	37.8	33.2	36.1	32.4	35.6
P-14	64.6	61	70	67.5	76.5	75	78.1	76.8
P-15	32.3	29.1	31.3	27.7	30.1	25.7	29.9	25.2
P-16	35.5	32	37.2	33.4	42.2	37.7	44.4	39.6

Table 13 Total factor errors of pressures at Fn=0.1 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and JONSWAP spectrum: Sea States 5 and 6

Fn=0.1	JONSWAP			
	Sea State 5		Sea State 6	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	85.5	86	85.6	86.1
P-2	27.5	24.1	27.8	24.4
P-3	44.4	36	44.2	36.4
P-4	52.7	46.9	52.1	46.9
P-5	63.7	47	62.2	46.4
P-6	75.1	68.5	76.2	69.7
P-7	71.1	60	72	60.7
P-8	66.6	64.9	69.4	67.5
P-9	53.4	47.5	53.4	47.9
P-10	46	47.7	46.5	48.1
P-11	50.2	51.8	50.8	52.9
P-12	28.9	33.2	28.6	33.1
P-13	32.7	35.8	32.1	35.4
P-14	77.5	76.1	78.8	77.5
P-15	30	25.4	29.8	24.9
P-16	43.5	38.8	45.4	40.5

Table 14 Total factor errors of pressures at Fn=0.2 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and ITTC spectrum: Sea States 4, 5, 6 and 7

Fn=0.2	ITTC							
	Sea State 4		Sea State 5		Sea State 6		Sea State 7	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	82.9	83.7	84.2	85.2	85.2	86.4	85.4	86.7
P-2	18.3	11.2	19.4	11.1	21	11.3	21.5	11.5
P-3	16	15.4	16.2	16.3	16.8	18.2	17.1	19
P-4	20.6	13.7	21.3	16.5	22	20.3	22.2	21.4
P-5	32.9	10.6	34.7	10.7	36.5	11	36.9	11.1
P-6	91.9	91	87.3	85	81	78.1	79.1	76.3
P-7	59.1	33.4	65.8	34.9	76.5	38.5	80.3	40.2
P-8	27.6	47	25.8	43.7	24.5	40.9	24.5	40.5
P-9	29.3	45.9	26.1	41.9	21.9	36.9	20.6	35.4
P-10	37.2	55.7	33.9	49	29.4	40.3	28	37.8
P-11	72.3	54.2	69.6	55.3	65.6	56.4	64.4	56.7
P-12	24.6	19.1	23.9	19.5	23.6	20.4	23.7	20.8
P-13	25.3	23.6	24	22.9	22.6	22.4	22.2	22.3
P-14	65.4	58.5	61	56.8	54.6	53.8	52.7	52.7
P-15	39.8	33	39	33	37.9	33.1	37.5	33.1
P-16	39.2	59	38.3	50.7	39.9	44.6	41	43.7

Table 15 Total factor errors of pressures at Fn=0.2 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and JONSWAP spectrum: Sea States 5 and 6

Fn=0.2	JONSWAP			
	Sea State 5		Sea State 6	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	85.3	86.6	85.5	86.8
P-2	21.3	11.4	21.7	11.5
P-3	17	18.7	17.2	19.3
P-4	22.2	21	22.3	21.9
P-5	36.8	11	37.1	11.1
P-6	79.9	76.9	78.4	75.6
P-7	78.8	39.5	82.1	41.1
P-8	24.5	40.6	24.5	40.4
P-9	21.1	36	20	34.8
P-10	28.6	38.7	27.5	36.8
P-11	64.9	56.6	64	56.8
P-12	23.6	20.6	23.7	21
P-13	22.3	22.3	22.1	22.3
P-14	53.4	53.1	51.9	52.2
P-15	37.7	33.1	37.3	33.1
P-16	40.5	43.9	41.5	43.3

Table 16 Total factor errors of pressures at Fn=0.29 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and ITTC spectrum: Sea States 4, 5, 6 and 7

Fn=0.29	ITTC							
	Sea State 4		Sea State 5		Sea State 6		Sea State 7	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	85.9	87.3	85.9	87.5	85.9	87.6	85.8	87.6
P-2	24.7	15.2	28.2	17.2	33.5	20.5	35.3	21.7
P-3	20.3	18	18.7	17.4	17.1	17.2	16.6	17.2
P-4	28.7	13.6	27	15.8	25.6	19	25.2	20.1
P-5	39	16.2	38.3	15.1	39	13.4	39.5	12.8
P-6	397.8	269.2	295	211	207.7	159.3	187.9	147.2
P-7	60.1	23.4	63	23.8	70.6	26.1	74.1	27.4
P-8	56.1	13.8	49.7	15.7	41.5	19.1	39	20.4
P-9	45.5	23.4	41.2	25.1	35.6	27.8	33.9	28.7
P-10	50.7	47	53.4	47.5	55.9	47.6	56.3	47.3
P-11	199.2	95.9	184.3	99.5	160.1	101.4	151.4	101
P-12	74.4	71.1	76.8	78.6	79.8	89.9	80.2	93.8
P-13	69.6	69.2	69	71	66.5	72.7	65.3	73.1
P-14	423	125.7	376.7	120.5	303	112	277.8	109
P-15	132.1	55.9	125.2	58.5	114.3	63.5	110.3	65.6
P-16	170.4	48.4	145	46.1	115.9	46.2	108.1	47

Table 17 Total factor errors of pressures at Fn=0.29 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and JONSWAP spectrum: Sea States 5 and 6

Fn=0.29	JONSWAP			
	Sea State 5		Sea State 6	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	85.8	87.6	85.8	87.6
P-2	34.6	21.2	36.1	22.2
P-3	16.8	17.2	16.5	17.2
P-4	25.3	19.7	25.1	20.5
P-5	39.2	13.1	39.7	12.6
P-6	195.3	151.8	180.4	142.7
P-7	72.6	26.8	75.7	27.9
P-8	39.9	19.9	37.8	21
P-9	34.5	28.3	33.1	29.1
P-10	58.2	47.4	56.4	47.2
P-11	154.8	101.3	147.5	100.8
P-12	80	92.3	80.5	95.6
P-13	65.8	73	64.7	73.2
P-14	287.5	110.2	266.6	107.8
P-15	111.8	64.8	108.3	66.6
P-16	110.9	46.6	104.8	47.3

Table 18 Total factor errors of pressures at Fn=0.37 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and ITTC spectrum: Sea States 4, 5, 6 and 7

Fn=0.37	ITTC							
	Sea State 4		Sea State 5		Sea State 6		Sea State 7	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	84.4	87	84.2	86.9	84	86.7	84	86.7
P-2	37.4	26.6	39.2	27.4	43.5	29.3	45.2	30.1
P-3	28.1	16.2	24.1	15.1	19.9	14.4	18.8	14.3
P-4	24.9	18.4	24.2	20.4	23.6	23.2	23.4	24.1
P-5	26.8	16.2	26.5	15.6	27.7	15	28.4	14.8
P-6	37.6	27.3	37.3	31	38.1	36.4	38.5	38.1
P-7	20.8	20.1	23.9	18.7	29.2	17.2	31.2	16.8
P-8	43.6	29.4	39.6	27.7	34.4	26.1	32.7	25.8
P-9	56.7	40.5	51.6	38.3	45	36.1	42.9	35.6
P-10	71.4	44	73.3	46.2	77.1	50	78.6	51.4
P-11	123.6	80.7	111.9	78	97.3	75.5	92.9	75.1
P-12	81.4	75.5	80.8	77.9	79.4	81.5	78.8	82.7
P-13	114.3	103.1	116.7	109.5	119.6	120	120.5	124.1
P-14	303.7	213.6	265.1	197.3	215.6	176	201.3	169.9
P-15	180.4	173.1	187.5	187.2	197.5	207.9	200.4	214.5
P-16	356.5	141.6	296.6	122.6	227.8	103.3	209	98.9

Table 19 Total factor errors of pressures at Fn=0.37 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and JONSWAP spectrum: Sea States 5 and 6

Fn=0.37	JONSWAP			
	Sea State 5		Sea State 6	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	84	86.7	84	86.7
P-2	44.5	29.7	45.9	30.4
P-3	19.2	14.3	18.4	14.3
P-4	23.5	23.8	23.4	24.5
P-5	28	14.9	28.7	14.8
P-6	38.3	37.4	38.7	38.8
P-7	30.4	16.9	32	16.6
P-8	33.4	25.9	32	25.7
P-9	43.7	35.8	42	35.3
P-10	77.9	50.8	79.2	52
P-11	94.5	75.2	91	74.9
P-12	79.1	82.2	78.6	83.2
P-13	120.2	122.5	120.9	125.9
P-14	206.7	172.2	195.3	167.3
P-15	199.4	212	201.7	217.5
P-16	215.9	100.4	201	97.1

Table 20 Total factor errors of pressures at Fn=0.39 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and ITTC spectrum: Sea States 4, 5, 6 and 7

Fn=0.39	ITTC							
	Sea State 4		Sea State 5		Sea State 6		Sea State 7	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	82.6	85.3	82.3	85.1	82	84.9	81.9	84.9
P-2	38.7	29	41.8	29.7	47	31.7	48.9	32.5
P-3	31.4	29	26.1	24.9	20.5	20.9	19.1	20
P-4	27.6	29.5	26	28.1	24.8	28	24.3	28.3
P-5	27.3	28.6	26.7	25.3	27.5	22	28.1	21.1
P-6	43	57.1	41.4	52	40.5	48.3	40.5	47.8
P-7	26.7	39.3	26.7	35.7	28	31.6	28.7	30.4
P-8	94	58.3	86.1	53.8	74.7	47.6	70.9	45.5
P-9	109.5	74.4	100.3	69	87.1	61.5	82.7	59.1
P-10	90.8	53.8	90.8	54	91.3	54.9	91.6	55.4
P-11	126	119.4	114.2	107.3	98.9	93.5	94.3	89.8
P-12	102.7	114.9	97.8	107.7	90	98.5	87.2	95.6
P-13	132.7	123.5	133.9	126.3	135.9	133	136.7	136
P-14	308.1	284.1	270.9	249.7	222	207.2	207.7	195.4
P-15	196.2	216.2	203.9	222.5	212.5	232	214.4	234.8
P-16	292.5	315.8	243.1	259.9	189	196.8	175.1	180

Table 21 Total factor errors of pressures at Fn=0.39 for WAVELOAD and PRECAL based on experimental data of Ref. 5 and JONSWAP spectrum: Sea States 5 and 6

Fn=0.39	JONSWAP			
	Sea State 5		Sea State 6	
	WAVELOAD	PRECAL	WAVELOAD	PRECAL
P-1	82	84.9	81.9	84.9
P-2	48.1	32.2	49.6	32.9
P-3	19.7	20.3	18.6	19.6
P-4	24.4	28.2	24.1	28.4
P-5	27.8	21.4	28.4	20.8
P-6	40.5	47.9	40.5	47.6
P-7	28.4	30.8	29	29.9
P-8	72.4	46.3	69.3	44.7
P-9	84.4	60	80.8	58.1
P-10	91.5	55.1	91.8	55.6
P-11	96	91.2	92.4	88.3
P-12	88.3	96.7	85.9	94.3
P-13	136.4	134.7	137.1	137.4
P-14	213.2	199.9	201.8	190.6
P-15	213.8	233.8	215.2	236
P-16	180.1	186.2	169.3	173

FIGURES

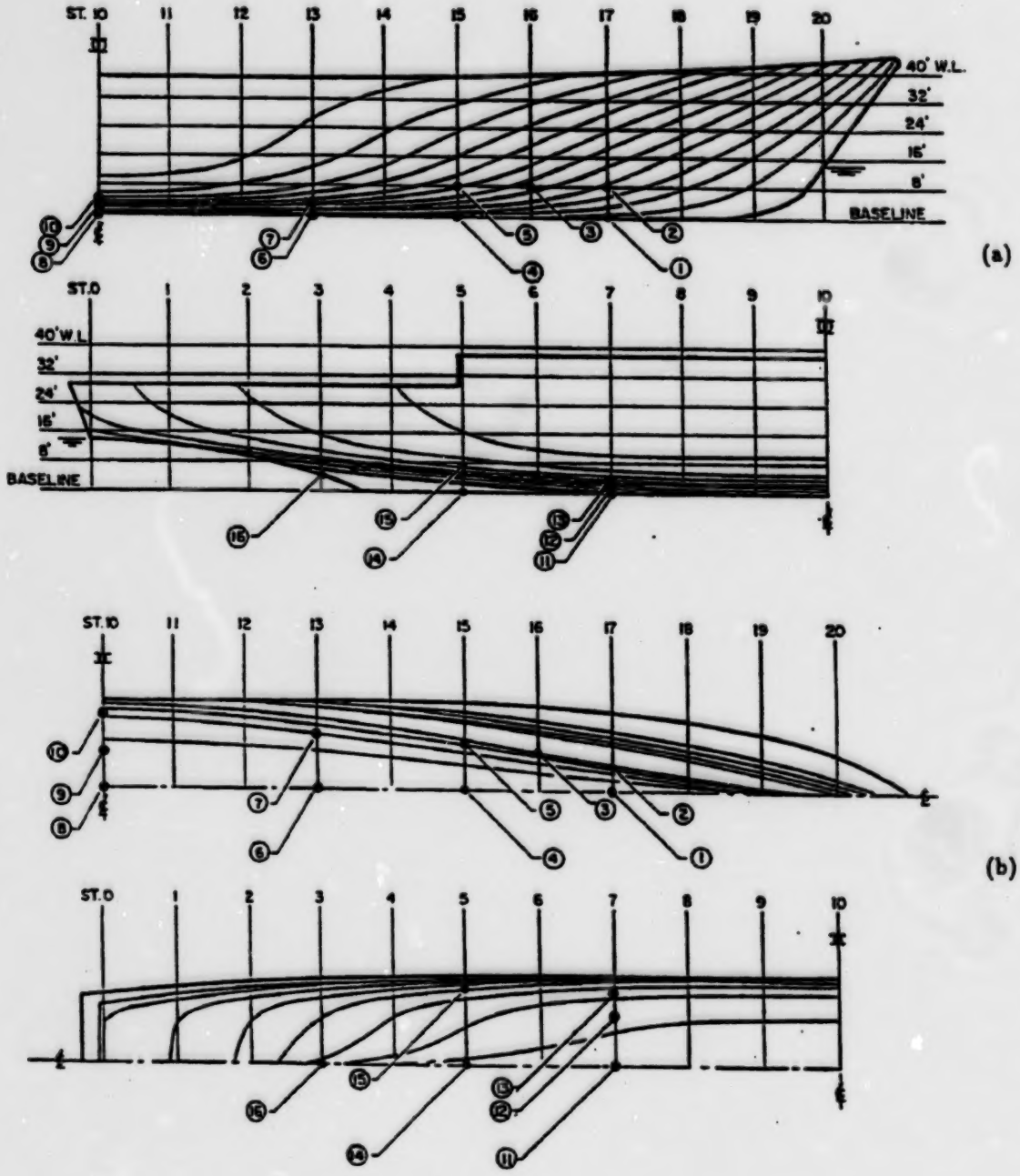


Figure 1. Lines drawing and locations of pressure transducers: (a) profile and (b) half-breadth plan

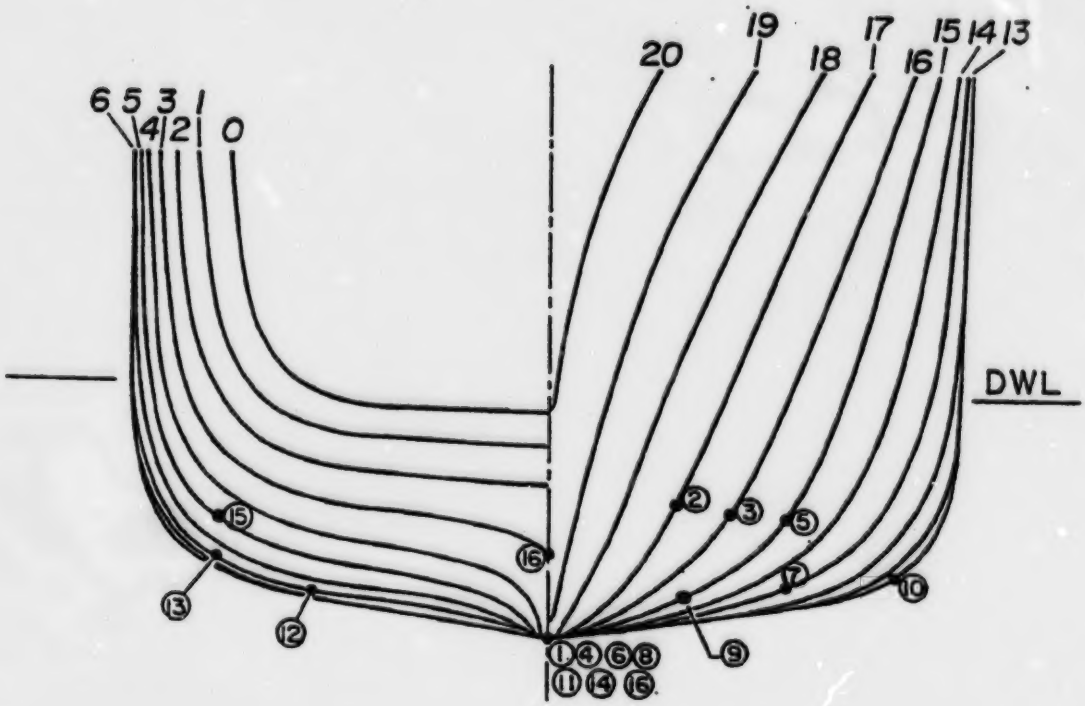
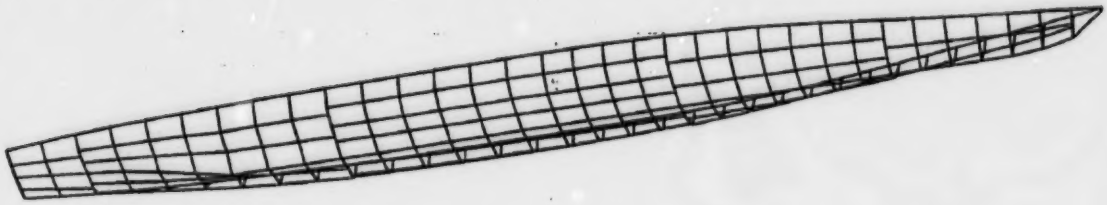
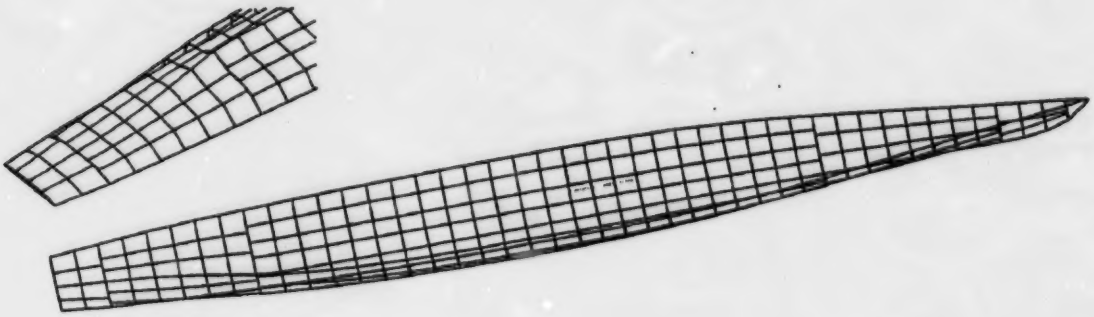


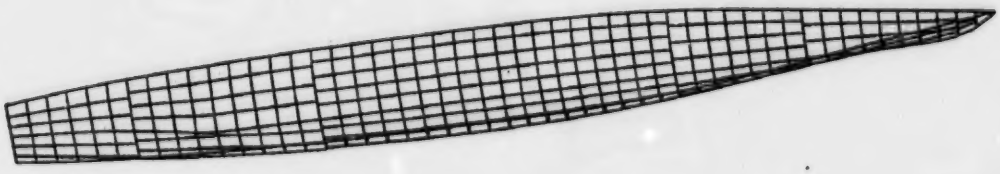
Figure 2. Body plan and location of pressure transducers



(a) 100 panels

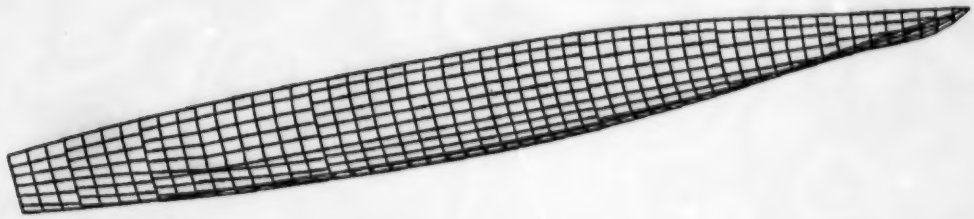


(b) 150 panels

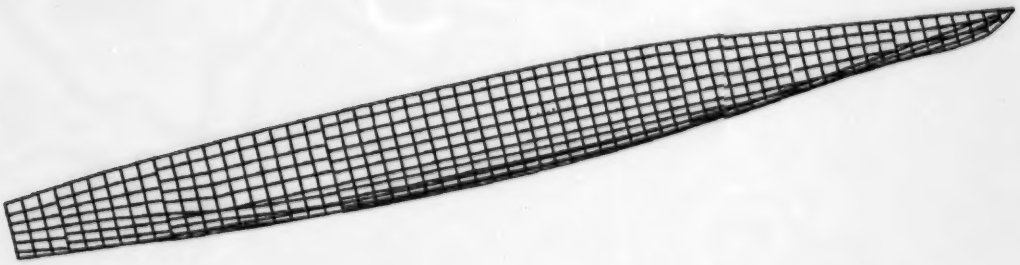


(c) 200 panels

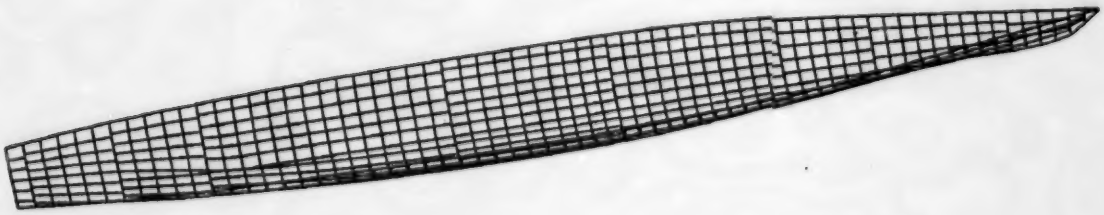
Figure 3. Geometric models with 100, 150, 200, 250, 300, 350, 400, 450 and 500 panels on the port side of hull



(d) 250 panels



(e) 300 panels

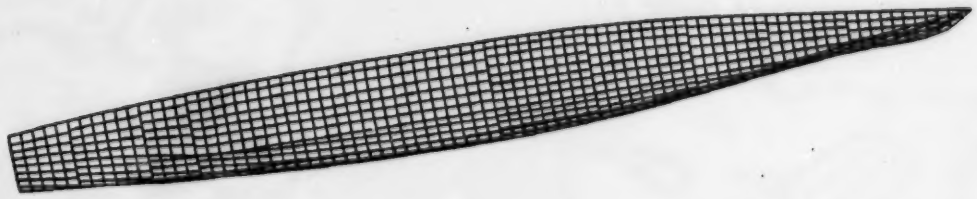


(f) 350 panels

Figure 3. (Continued). Geometric models with 100, 150, 200, 250, 300, 350, 400, 450 and 500 panels on the port side of hull

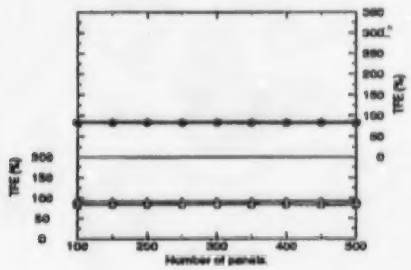
(g) 400 panels

(h) 450 panels



(i) 500 panels

Figure 3. (Continued). Geometric models with 100, 150, 200, 250, 300, 350, 400, 450 and 500 panels on the port side of hull



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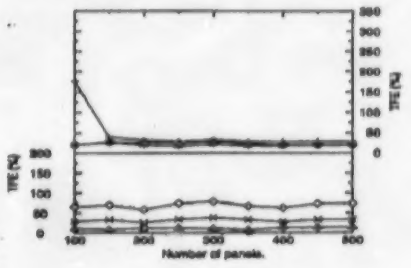
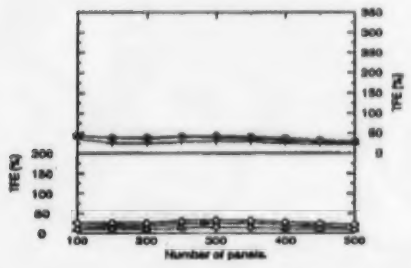
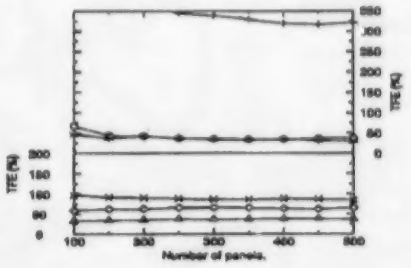


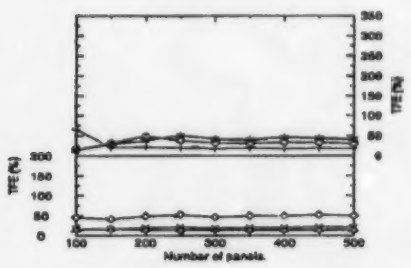
(e) Sensor 5



(b) Sensor 2



(f) Sensor 6



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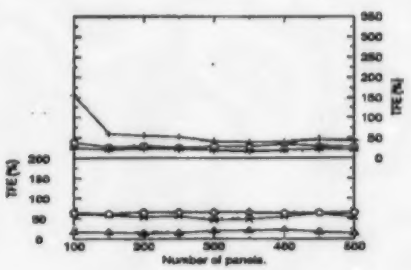
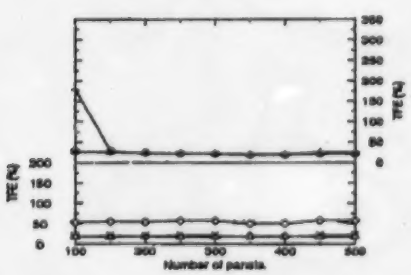
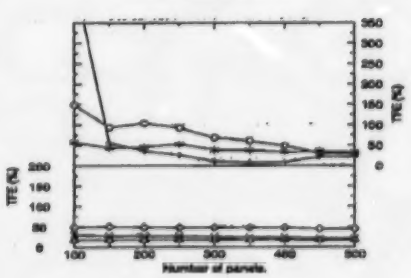


(g) Sensor 7

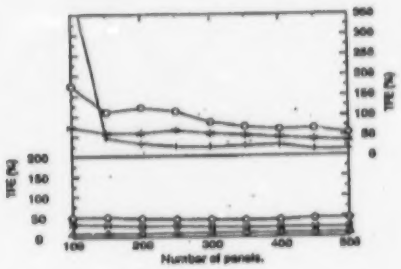


(d) Sensor 4

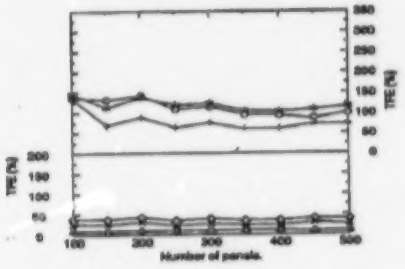


(h) Sensor 8

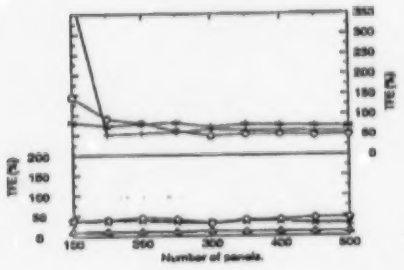
Figure 4. TFE's of predicted pressures on 16 transducer locations for 9 geometric models (with 100, 150, 200, 250, 300, 350, 400, 450 and 500 panels on the port side of hull) at Fn=0.0, 0.1, 0.2, 0.29, 0.37 and 0.39. (Symbols: Δ *Fn*=0.0; ◊ *Fn*=0.1; × *Fn*=0.2; + *Fn*=0.29; * *Fn*=0.37; o *Fn*=0.39)



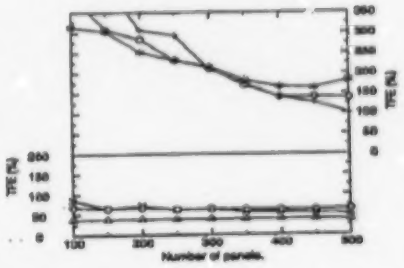
(i) Sensor 9



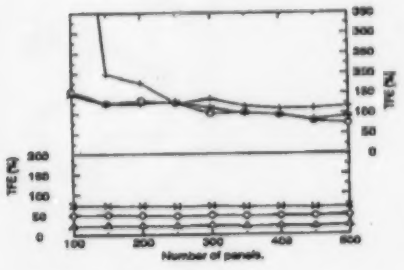
(m) Sensor 13



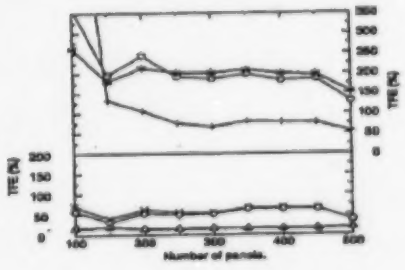
(j) Sensor 10



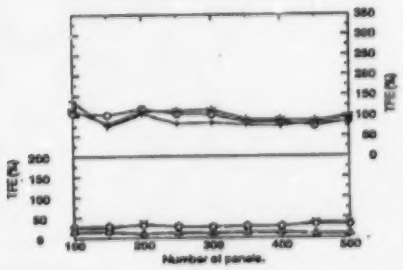
(n) Sensor 14



(k) Sensor 11



(o) Sensor 15



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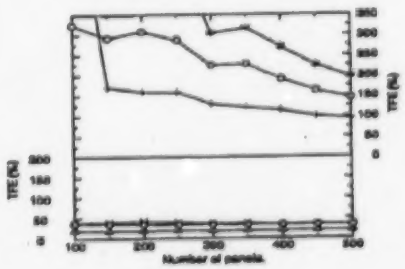


(p) Sensor 16

Figure 4. (Continued). TFE's of predicted pressures on 16 transducer locations for 9 geometric models (with 100, 150, 200, 250, 300, 350, 400, 450 and 500 panels on the port side of hull) at Fn=0.0, 0.1, 0.2, 0.29, 0.37 and 0.39. (Symbols: Δ Fn=0.0; $\diamond$ Fn=0.1; $\times$ Fn=0.2; + Fn=0.29; $*$ Fn=0.37; o Fn=0.39)

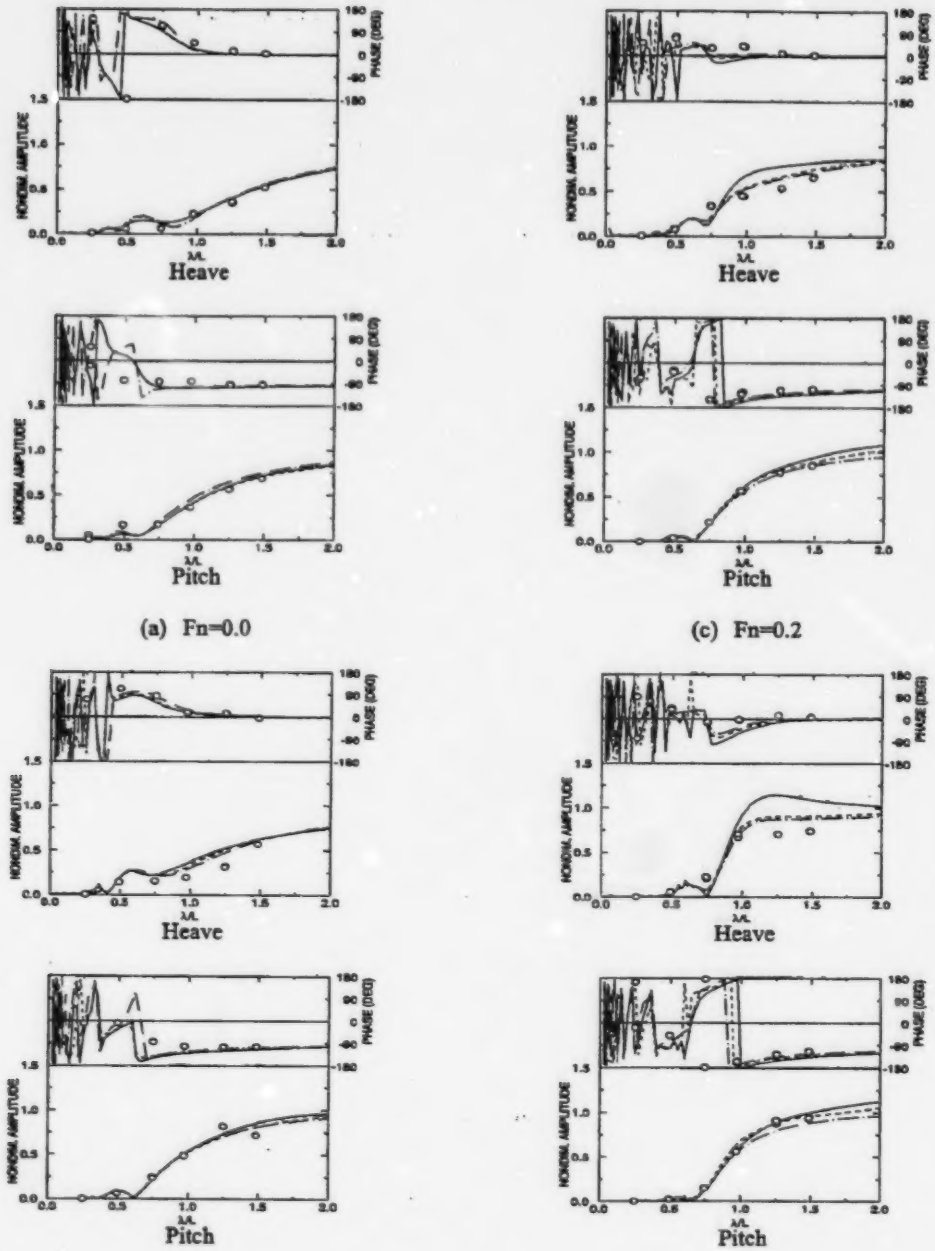
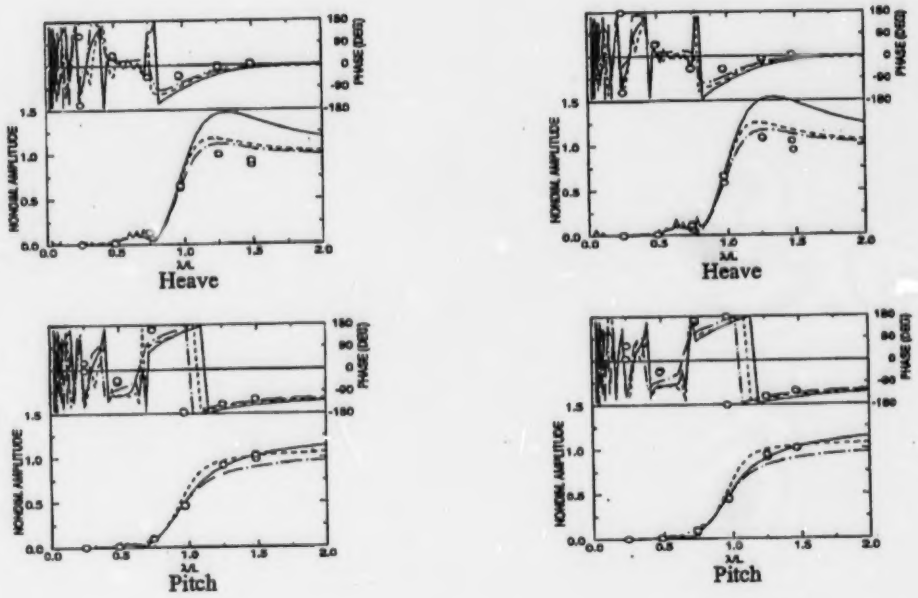
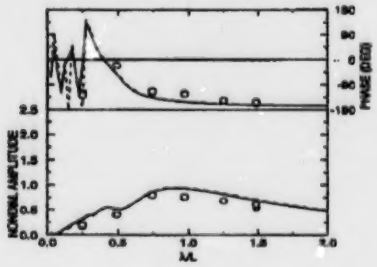


Figure 5. Comparison of measured transfer functions for heave and pitch motions and predictions by WAVELOAD, PRECAL and SHIPMO7. (Symbols: —WAVELOAD; --- PRECAL; —·— SHIPMO7; o experiment)



(e) Fn=0.37 (f) Fn=0.39

Figure 5. (Continued). Comparison of measured transfer functions for heave and pitch motions and predictions by WAVELOAD, PRECAL and SHIPMO7. (Symbols: — WAVELOAD; — PRECAL; —·— SHIPMO7; o experiment)



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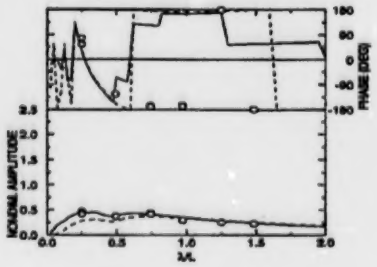
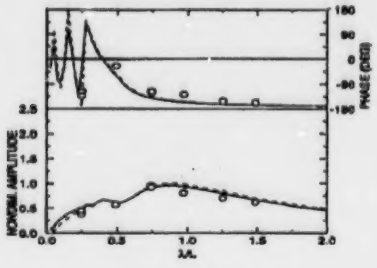


(e) Sensor 5



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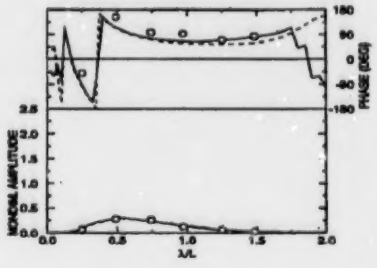
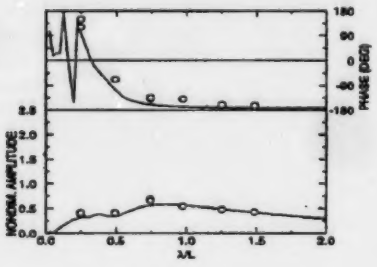


(f) Sensor 6



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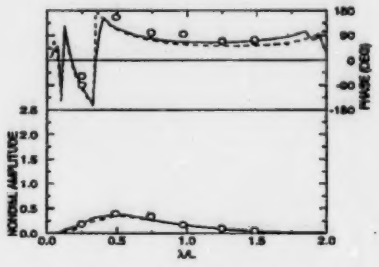

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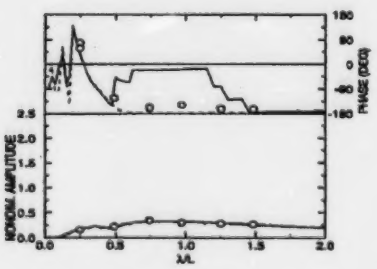
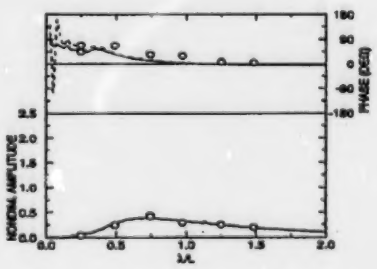
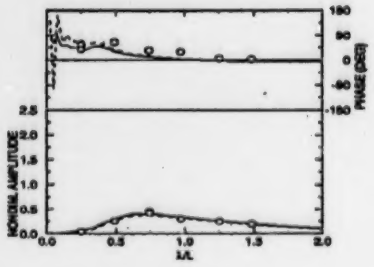


(d) Sensor 4

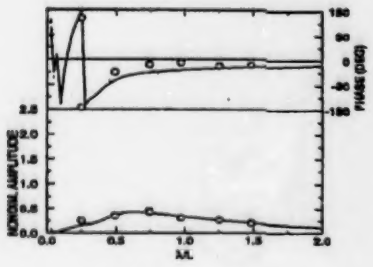


(h) Sensor 8

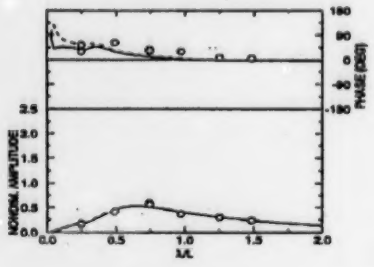
Figure 6. Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.0 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; --- PRECAL; o experiment)



(i) Sensor 9



(m) Sensor 13



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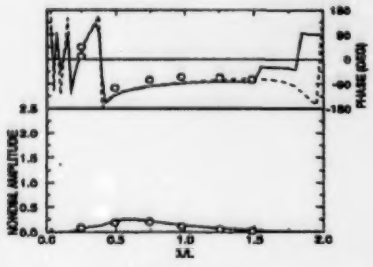
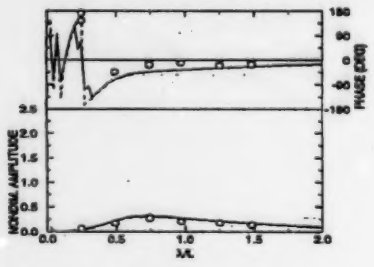


(n) Sensor 14



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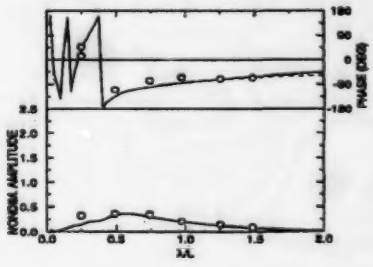

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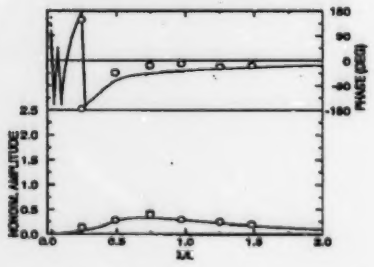

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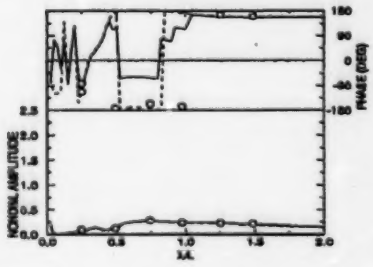
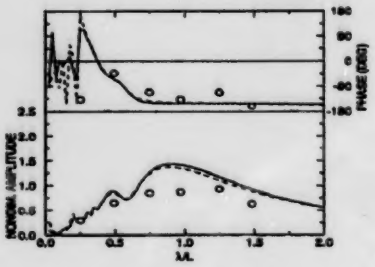
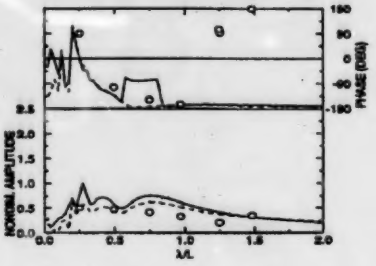


(p) Sensor 16

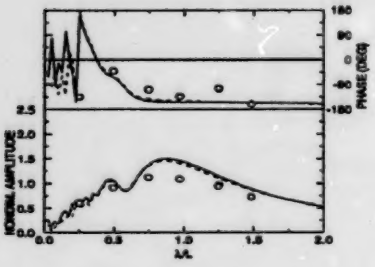
Figure 6. (Continued). Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.0 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; — PRECAL; o experiment)



(a) Sensor 1



(e) Sensor 5



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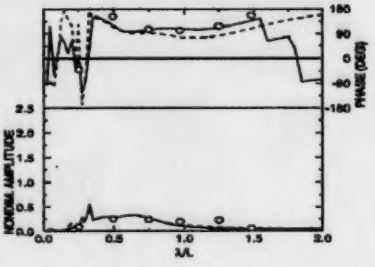

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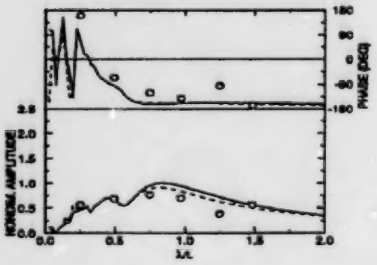
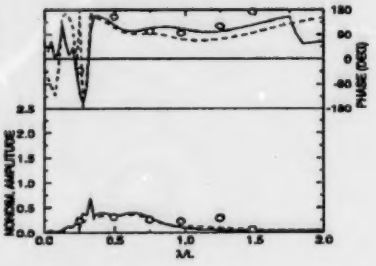
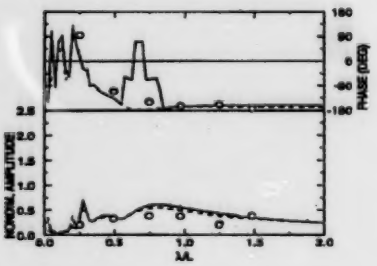


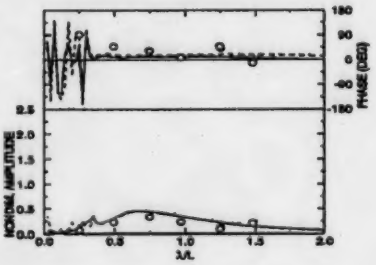
(c) Sensor 3



(g) Sensor 7

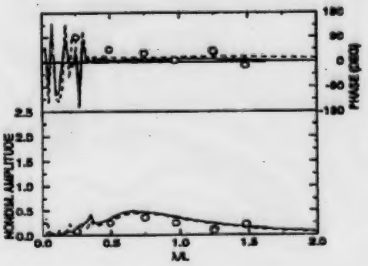


(d) Sensor 4

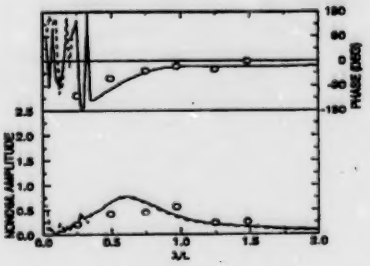


(h) Sensor 8

Figure 7. Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.1 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; — PRECAL; o experiment)



(i) Sensor 9



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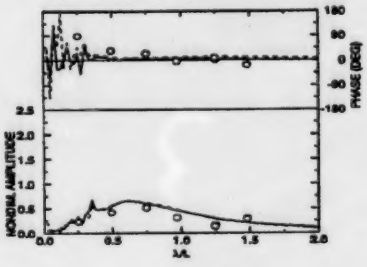

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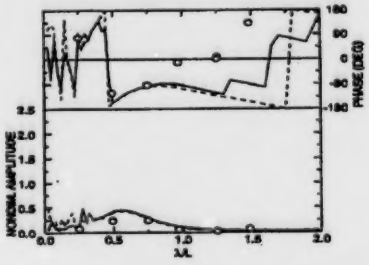

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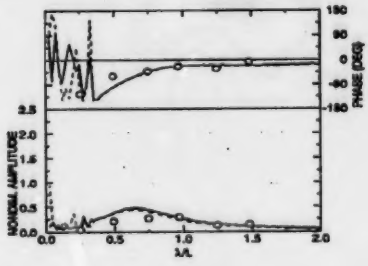
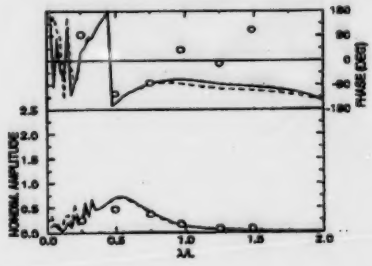
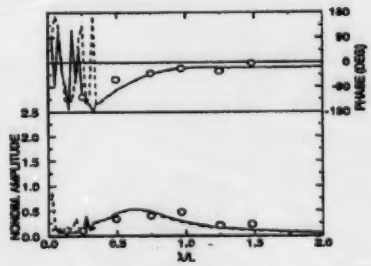


(k) Sensor 11



(o) Sensor 15



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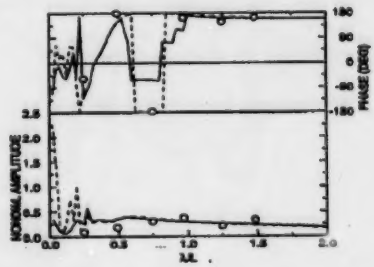
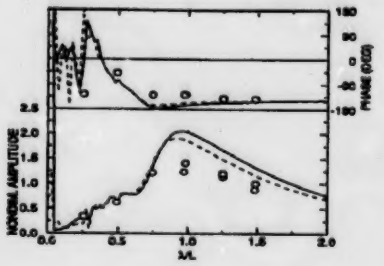
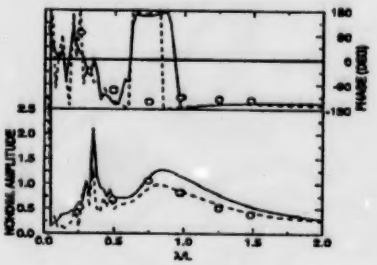


(p) Sensor 16

Figure 7. (Continued). Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.1 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; --- PRECAL; o experiment)



(a) Sensor 1



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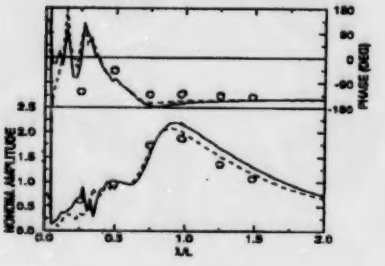
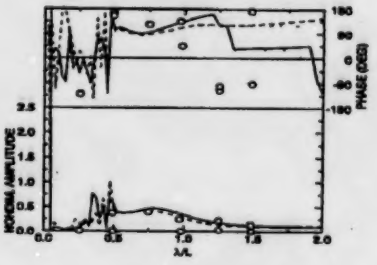
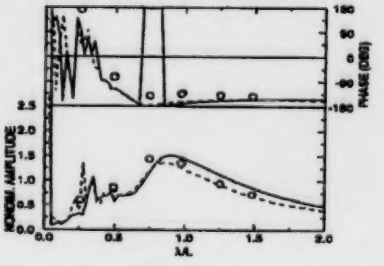


(b) Sensor 2



(f) Sensor 6



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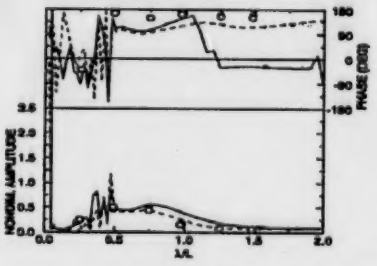

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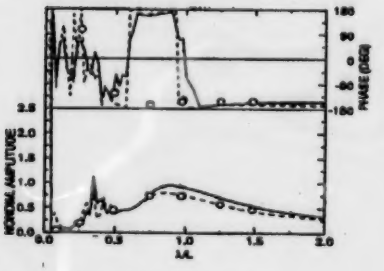
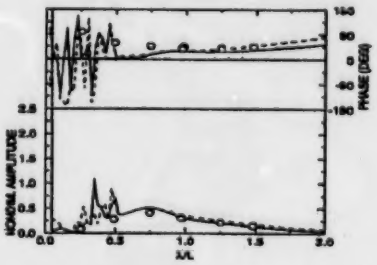
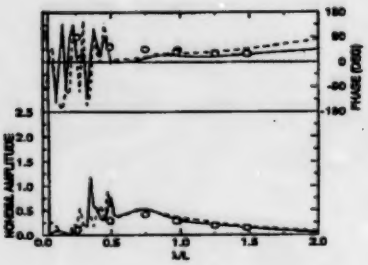


(d) Sensor 4

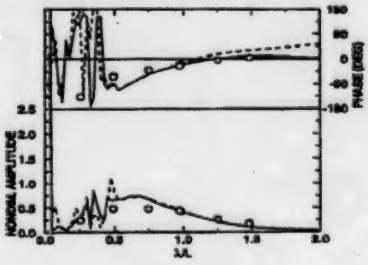


(h) Sensor 8

Figure 8. Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.2 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; --- PRECAL; o experiment)



(i) Sensor 9



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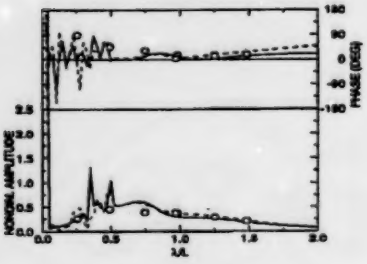

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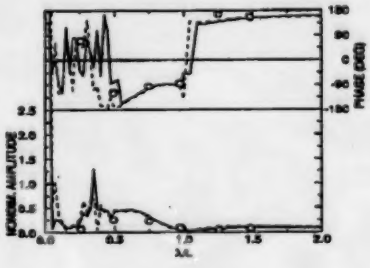

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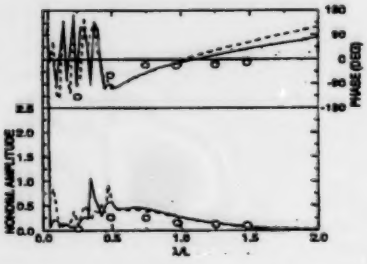
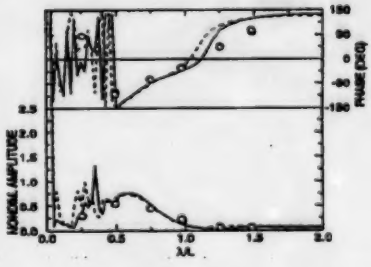
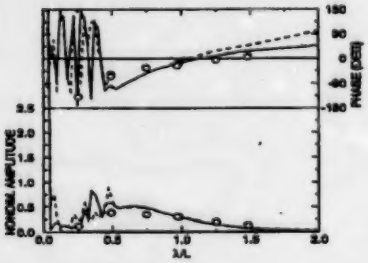


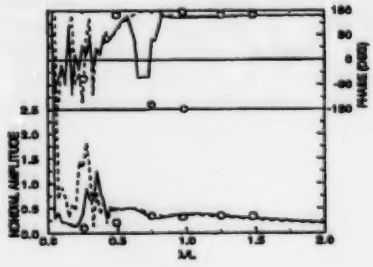
(k) Sensor 11



(o) Sensor 15

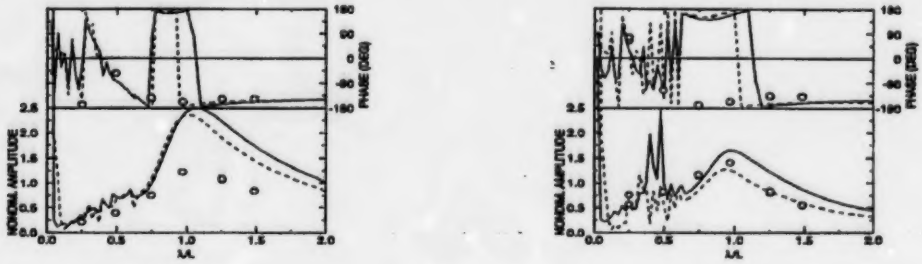


(l) Sensor 12



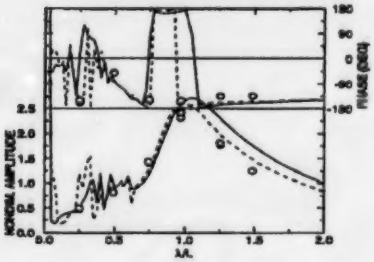
(p) Sensor 16

Figure 8. (Continued). Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.2 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; --- PRECAL; o experiment)



(a) Sensor 1

(e) Sensor 5



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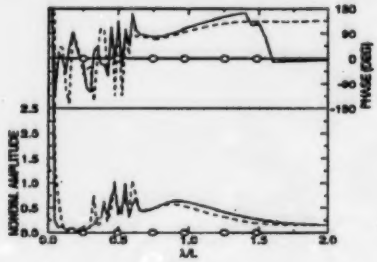
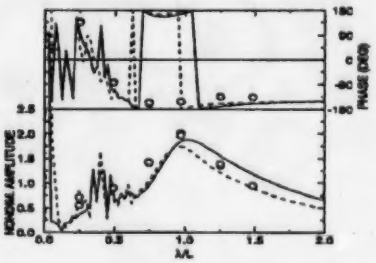


(f) Sensor 6



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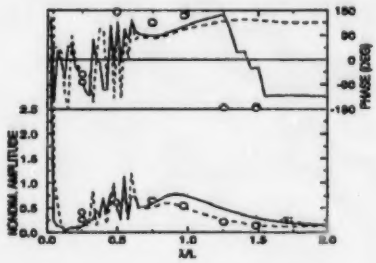
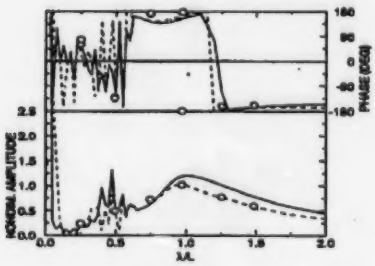
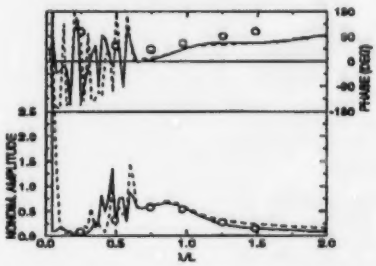


(g) Sensor 7

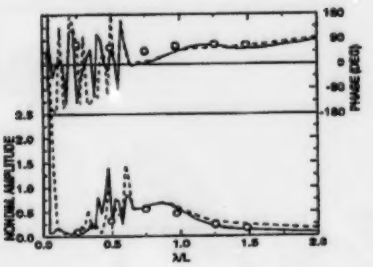


(d) Sensor 4

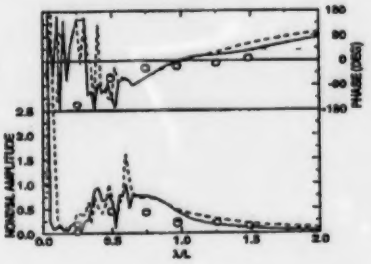


(h) Sensor 8

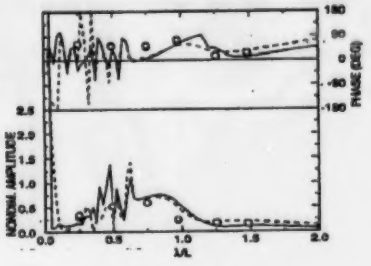
Figure 9. Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.29 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; --- PRECAL; o experiment)



(i) Sensor 9



(m) Sensor 13



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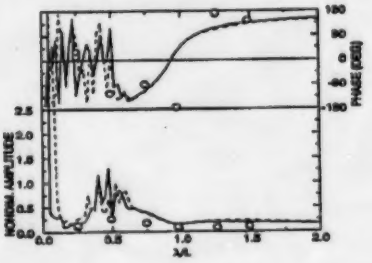
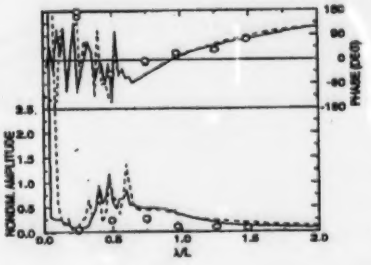
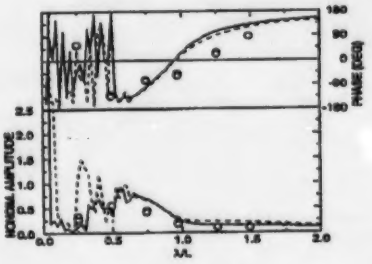


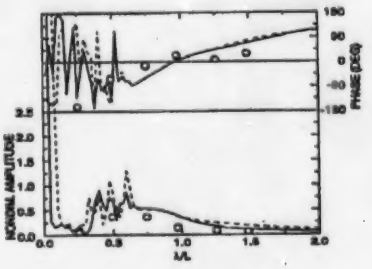
(n) Sensor 14



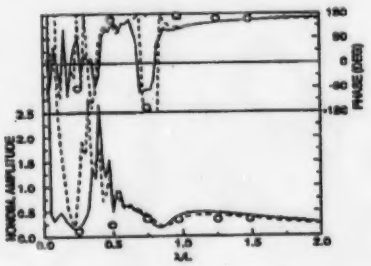
(k) Sensor 11



(o) Sensor 15

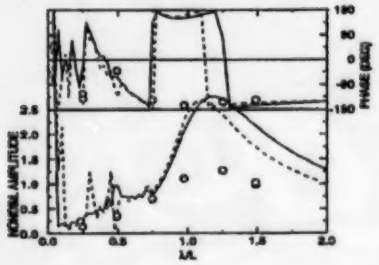


(l) Sensor 12

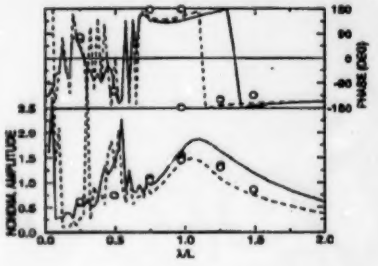


(p) Sensor 16

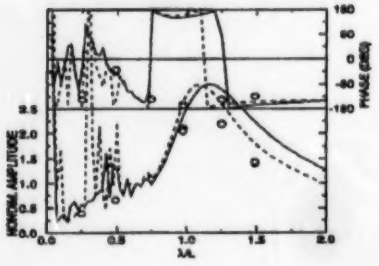
Figure 9. (Continued). Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.29 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; — PRECAL; o experiment)



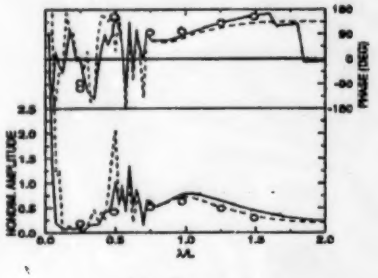
(a) Sensor 1



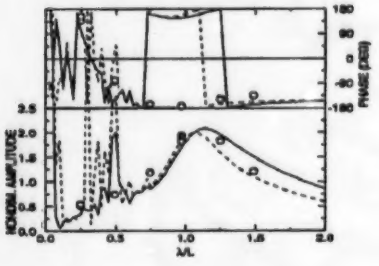
(e) Sensor 5



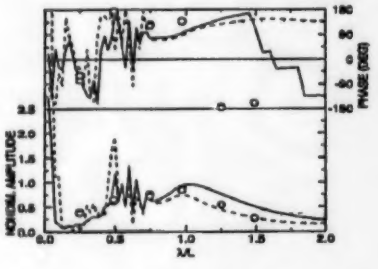
(b) Sensor 2



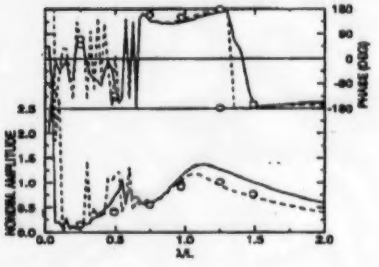
(f) Sensor 6



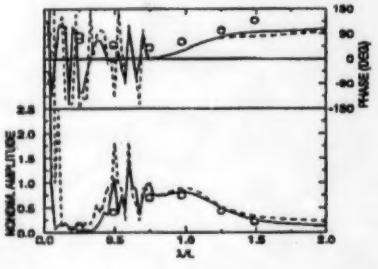
(c) Sensor 3



(g) Sensor 7

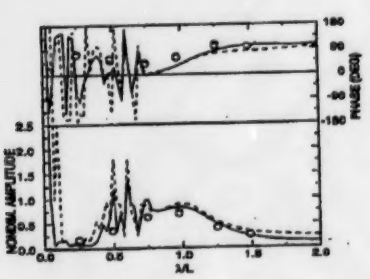


(d) Sensor 4

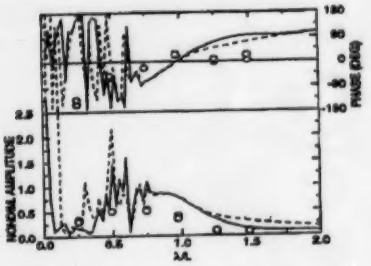


(h) Sensor 8

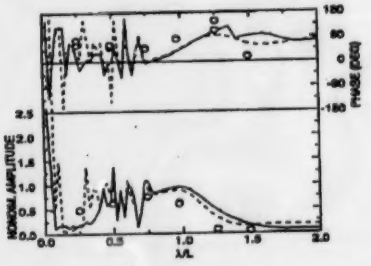
Figure 10. Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.37 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; --- PRECAL; o experiment)



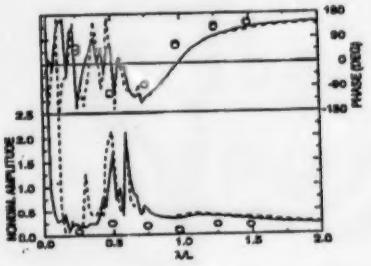
(i) Sensor 9



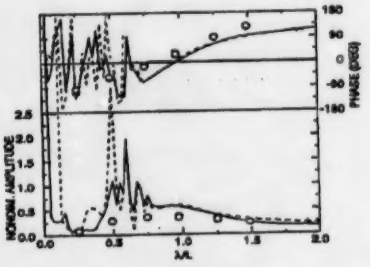
(m) Sensor 13



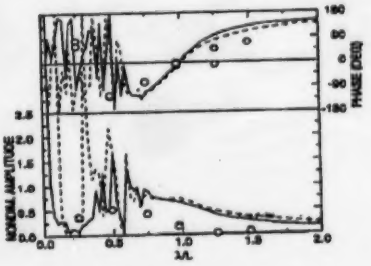
(j) Sensor 10



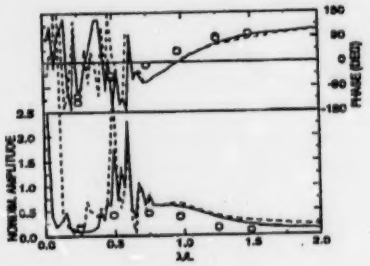
(n) Sensor 14



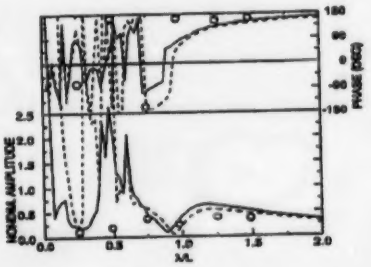
(k) Sensor 11



(o) Sensor 15

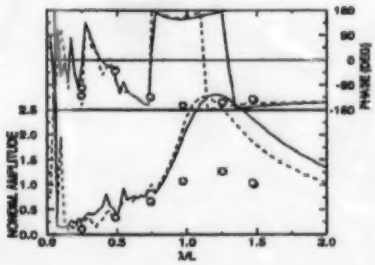


(l) Sensor 12

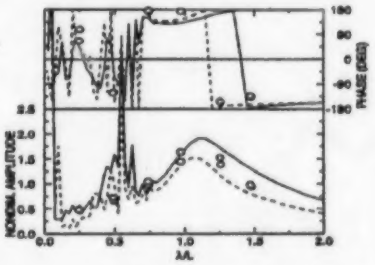


(p) Sensor 16

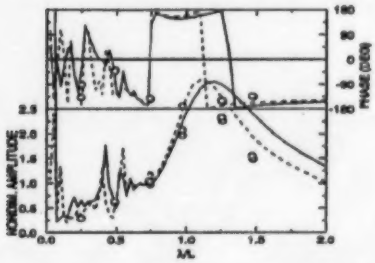
Figure 10. (Continued). Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.37 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; — PRECAL; o experiment)



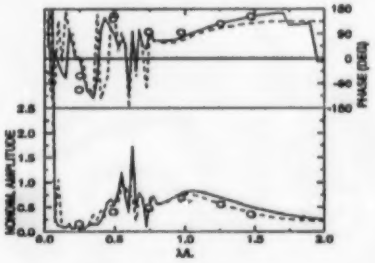
(a) Sensor 1



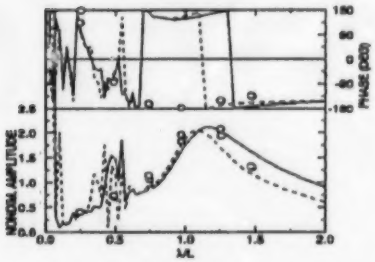
(e) Sensor 5



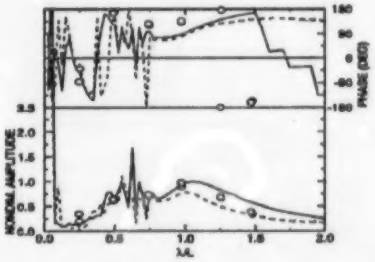
(b) Sensor 2



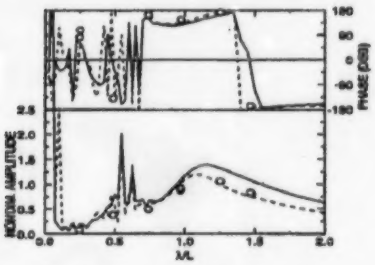
(f) Sensor 6



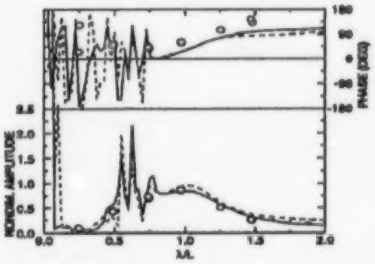
(c) Sensor 3



(g) Sensor 7

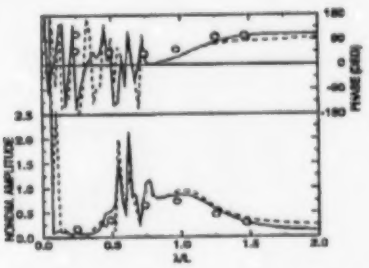


(d) Sensor 4

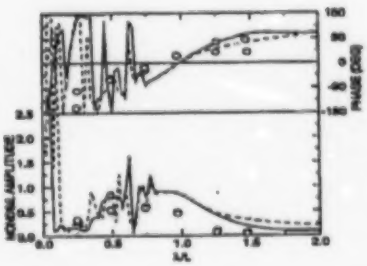


(h) Sensor 8

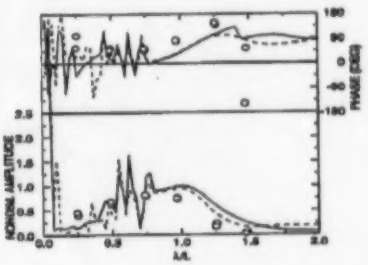
Figure 11. Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.39 and predictions by WAVELOAD and PRECAL. (Symbols: — WAVELOAD; --- PRECAL; o experiment)



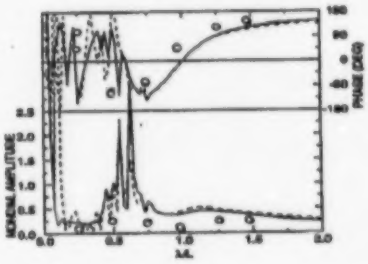
(i) Sensor 9



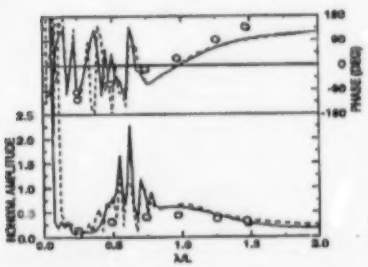
(m) Sensor 13



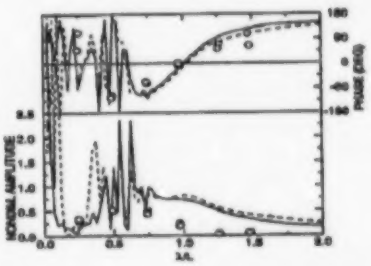
(j) Sensor 10



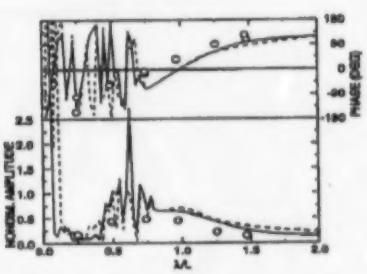
(n) Sensor 14



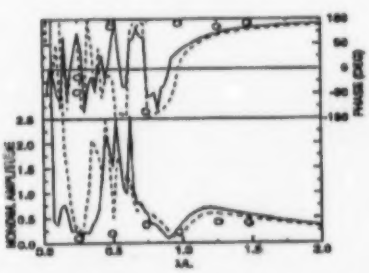
(k) Sensor 11



(o) Sensor 15



(l) Sensor 12



(p) Sensor 16

Figure 11. (Continued). Comparison of measured hydrodynamic pressures at 16 sensors at Fn=0.39 and predictions by WAVELOAD and PRECAL. (Symbols: —WAVELOAD; — PRECAL; o experiment)

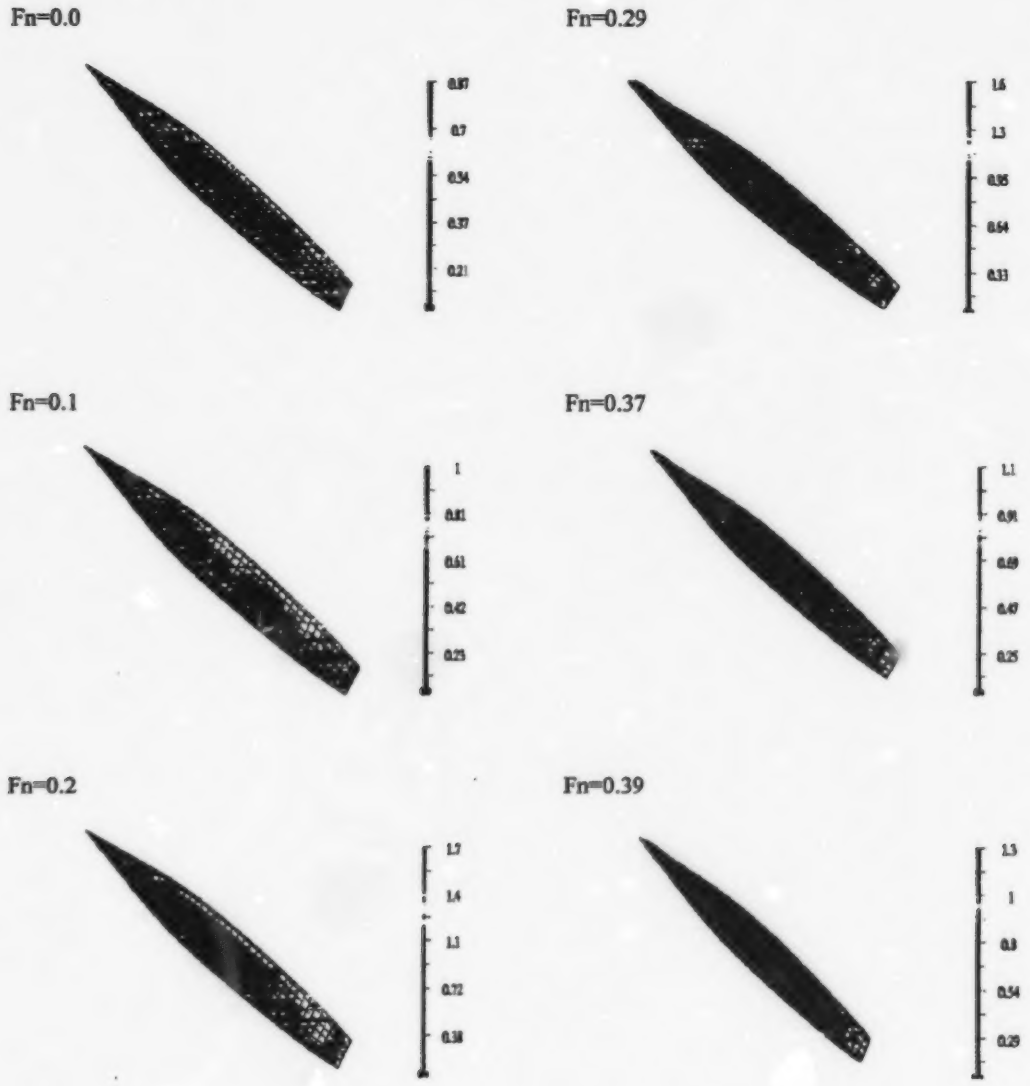
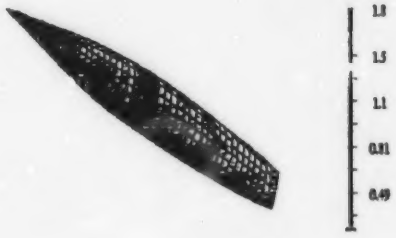


Figure 12. Predicted pressure distribution by WAVELOAD at $\lambda / L = 0.25$

Fn =0.0

Fn=0.29



Fn=0.1

Fn=0.37

Fn=0.2

Fn=0.39

Figure 13. Predicted pressure distribution by WAVELOAD at $\lambda / L = 0.5$

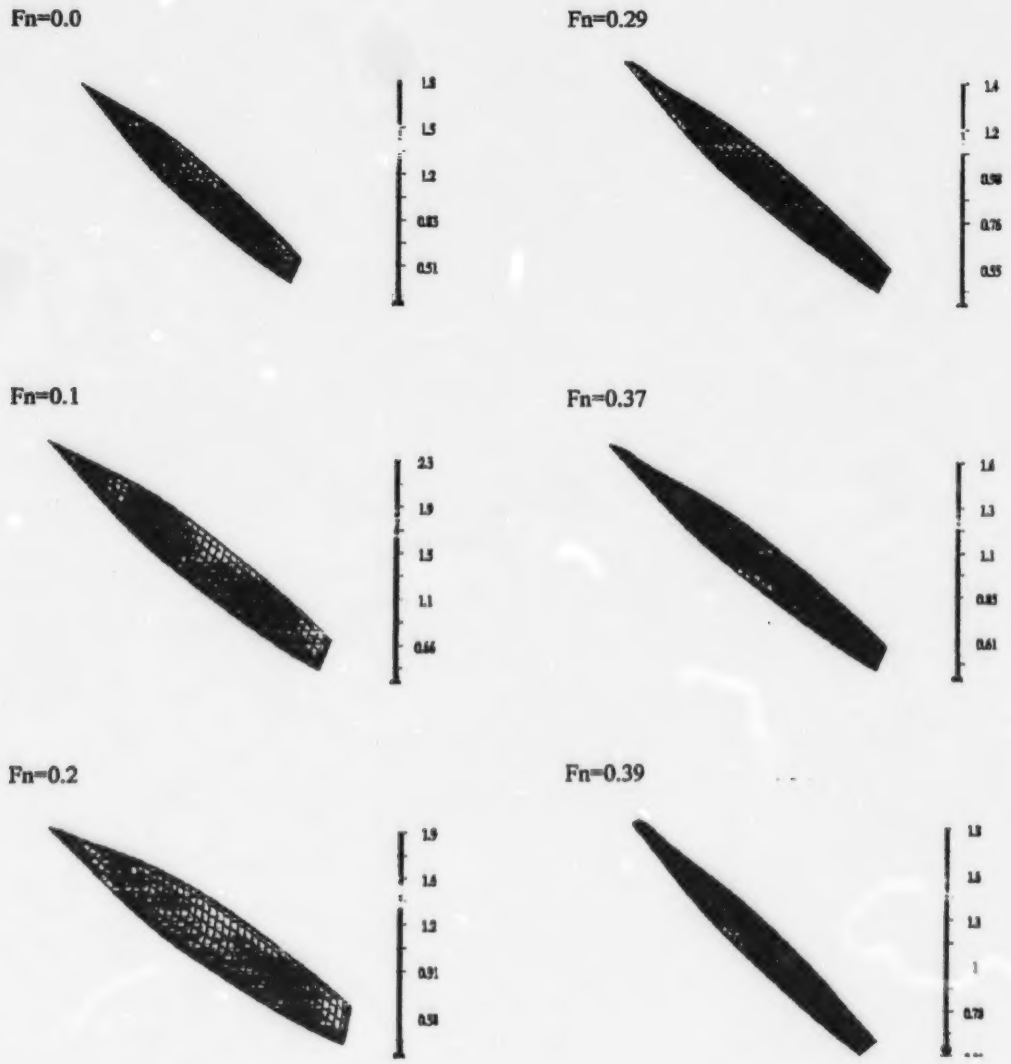


Figure 14. Predicted pressure distribution by WAVELOAD at $\lambda / L = 0.75$

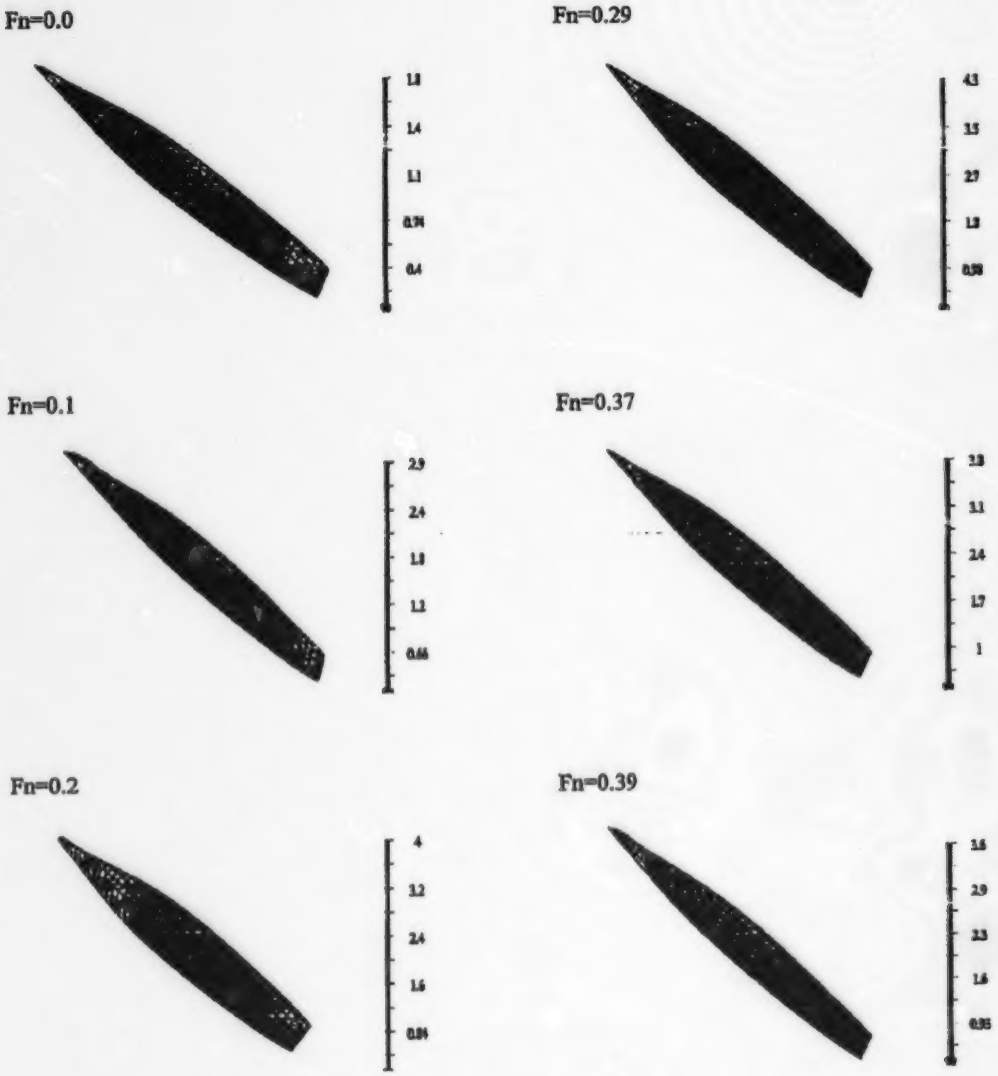


Figure 15. Predicted pressure distribution by WAVELOAD at $\lambda / L = 1.0$

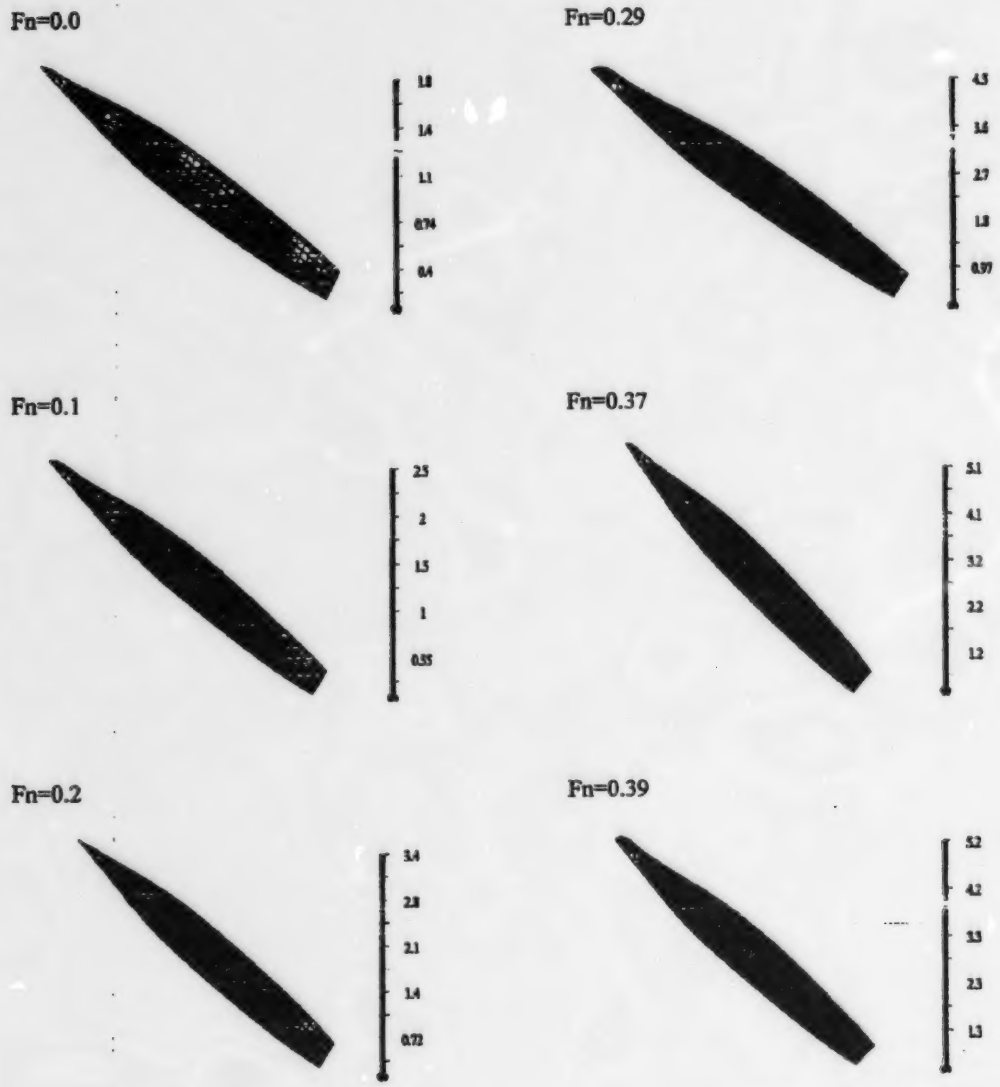


Figure 16. Predicted pressure distribution by WAVELOAD at $\lambda / L = 1.25$

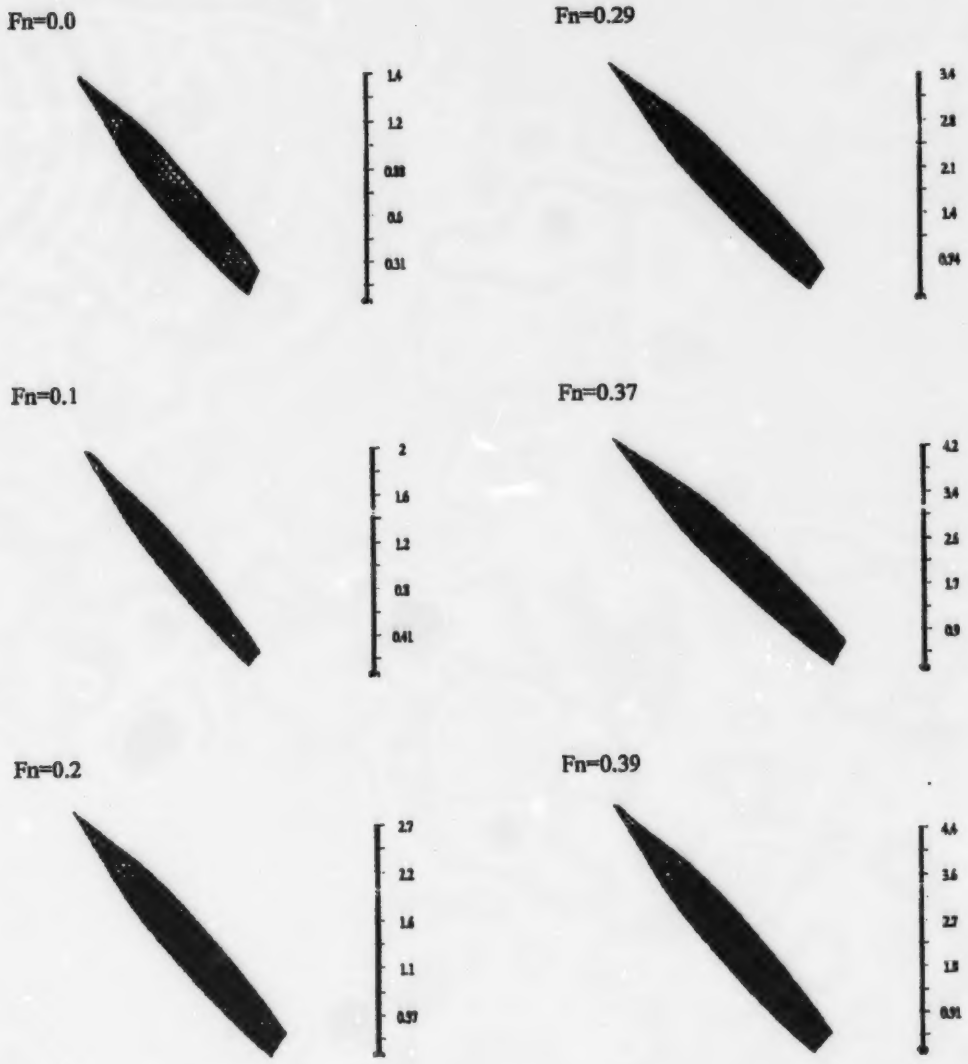
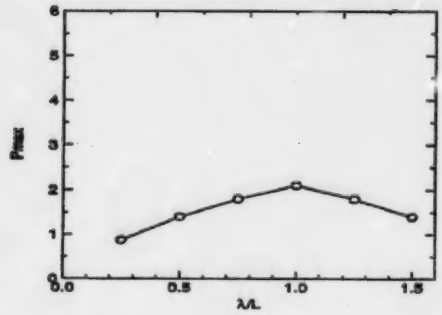
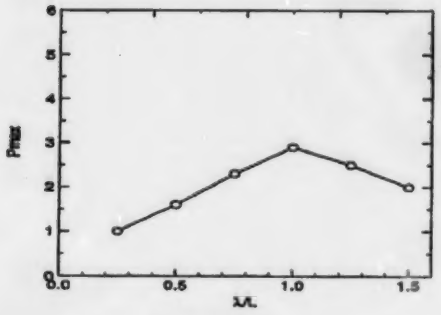


Figure 17. Predicted pressure distribution by WAVELOAD at $\lambda / L = 1.5$



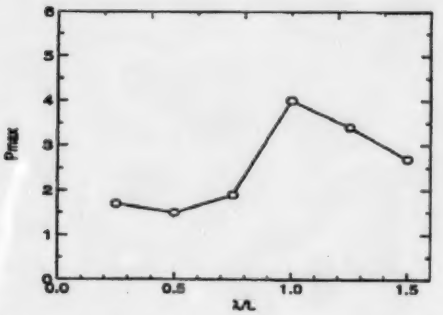
(a) Fn=0.0

Lambda/L	x	y	z
0.25	56.796	0.527	-0.895
0.5	59.387	0.119	-0.818
0.75	59.387	0.119	-0.818
1	59.387	0.119	-0.818
1.25	59.387	0.119	-0.818
1.5	59.387	0.119	-0.818



(b) Fn=0.1

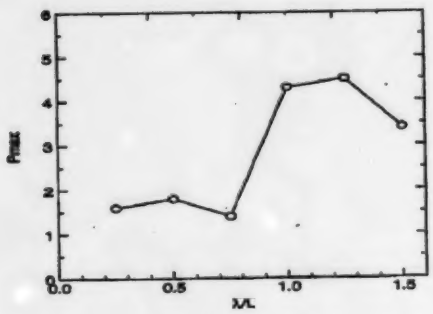
Lambda/L	x	y	z
0.25	-60.66	2.117	-0.209
0.5	56.796	0.527	-0.895
0.75	59.387	0.119	-0.818
1	59.387	0.119	-0.818
1.25	59.387	0.119	-0.818
1.5	59.387	0.119	-0.818



(c) Fn=0.2

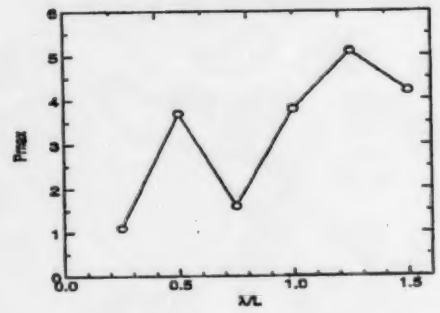
Lambda/L	x	y	z
0.25	-50.61	1.087	-1.554
0.5	-10.131	7.345	-1.232
0.75	48.92	1.791	-0.82
1	59.387	0.119	-0.818
1.25	59.387	0.119	-0.818
1.5	59.387	0.119	-0.818

Figure 18. Maximum nondimensional pressures for $\lambda / L = 0.25, 0.5, 0.75, 1.0, 1.25$ and 1.5 at six speeds



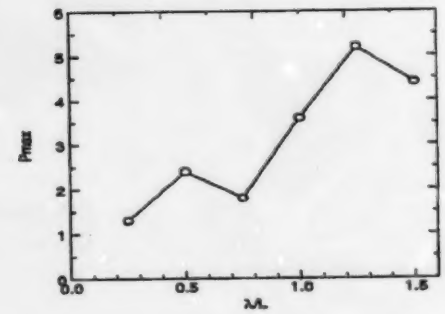
(d) Fn=0.29

Lambda/L	x	y	z
0.25	-60.66	2.117	-0.209
0.5	-60.66	2.117	-0.209
0.75	46.29	2.219	-0.851
1	59.387	0.119	-0.818
1.25	59.387	0.119	-0.818
1.5	59.387	0.119	-0.818



(e) Fn=0.37

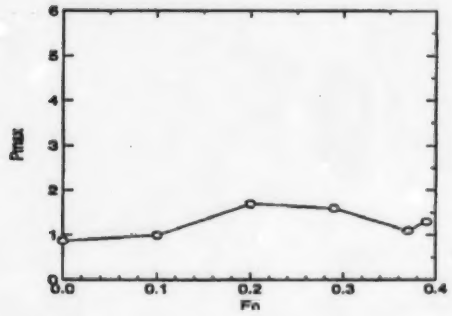
Lambda/L	x	y	z
0.25	-53.484	1.011	-1.226
0.5	33.159	4.346	-1.087
0.75	-21.708	7.151	-1.176
1	59.387	0.119	-0.818
1.25	59.387	0.119	-0.818
1.5	59.387	0.119	-0.818



(f) Fn=0.39

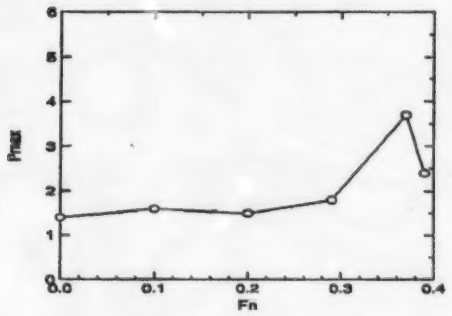
Lambda/L	x	y	z
0.25	-53.484	1.011	-1.226
0.5	-44.839	1.21	-2.41
0.75	-1.447	7.343	-1.242
1	59.387	0.119	-0.818
1.25	59.387	0.119	-0.818
1.5	59.387	0.119	-0.818

Figure 18. (Continued). Maximum nondimensional pressures for λ / L = 0.25, 0.5, 0.75, 1.0, 1.25 and 1.5 at six speeds



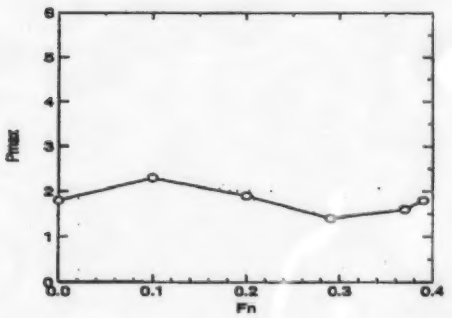
(a) $\lambda / L = 0.25$

Fn	x	y	z
0	56.796	0.527	-0.895
0.1	-60.66	2.117	-0.209
0.2	-50.606	1.087	-1.554
0.29	-60.661	2.117	-0.209
0.37	-53.484	1.011	-1.226
0.39	-53.484	1.011	-1.226



(b) $\lambda / L = 0.5$

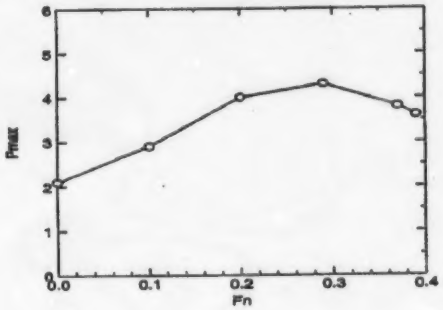
Fn	x	y	z
0	59.387	0.119	-0.818
0.1	56.796	0.527	-0.895
0.2	-10.131	7.345	-1.232
0.29	-60.661	2.117	-0.209
0.37	33.159	4.346	-1.087
0.39	-44.839	1.21	-2.405



(c) $\lambda / L = 0.75$

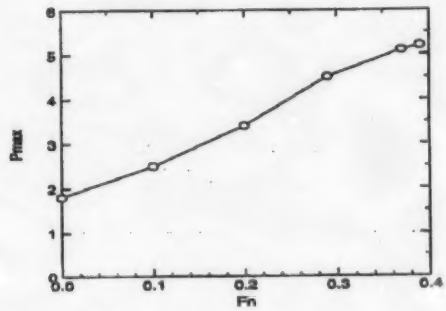
Fn	x	y	z
0	59.387	0.119	-0.818
0.1	59.387	0.119	-0.818
0.2	48.916	1.791	-0.82
0.29	46.29	2.219	-0.851
0.37	-21.708	7.151	-1.176
0.39	-1.447	7.343	-1.242

Figure 19. Maximum nondimensional pressures at Fn=0.0, 0.1, 0.2, 0.29, 0.37 and 0.39 for $\lambda / L = 0.25$, 0.5, 0.75, 1.0, 1.25 and 1.5



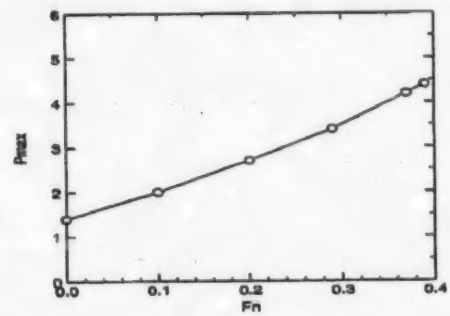
(d) $\lambda / L = 1.0$

Fn	x	y	z
0	59.387	0.119	-0.818
0.1	59.387	0.119	-0.818
0.2	59.387	0.119	-0.818
0.29	59.387	0.119	-0.818
0.37	59.387	0.119	-0.818
0.39	59.387	0.119	-0.818



(e) $\lambda / L = 1.25$

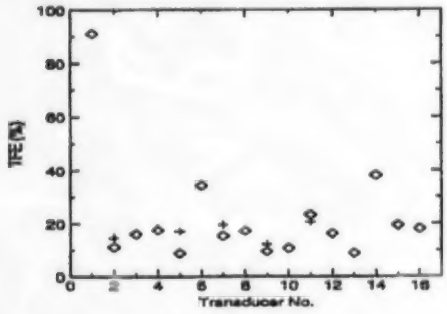
Fn	x	y	z
0	59.387	0.119	-0.818
0.1	59.387	0.119	-0.818
0.2	59.387	0.119	-0.818
0.29	59.387	0.119	-0.818
0.37	59.387	0.119	-0.818
0.39	59.387	0.119	-0.818



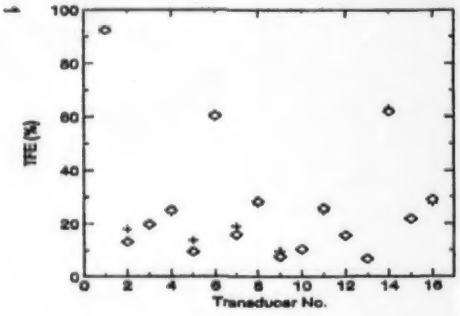
(f) $\lambda / L = 1.5$

Fn	x	y	z
0	59.387	0.119	-0.818
0.1	59.387	0.119	-0.818
0.2	59.387	0.119	-0.818
0.29	59.387	0.119	-0.818
0.37	59.387	0.119	-0.818
0.39	59.387	0.119	-0.818

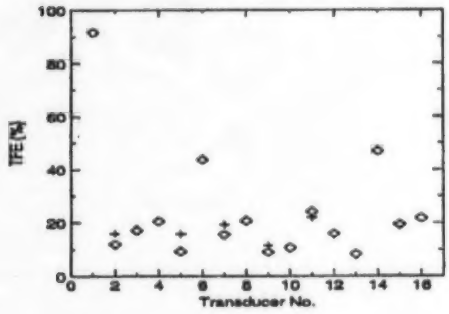
Figure 19. (Continued). Maximum nondimensional pressures at Fn=0.0, 0.1, 0.2, 0.29, 0.37 and 0.39 for λ / L = 0.25, 0.5, 0.75, 1.0, 1.25 and 1.5



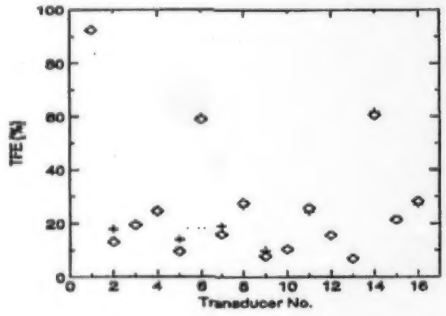
ITTC: Hs=1.88m, T=8.8s at Fn=0.0



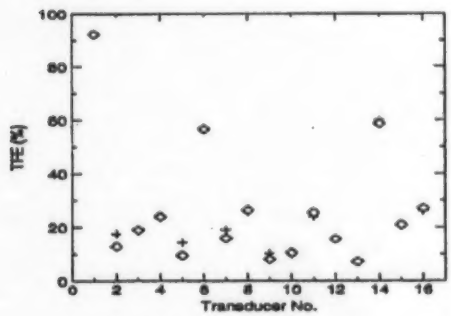
ITTC: Hs=7.5m, T=15s at Fn=0.0



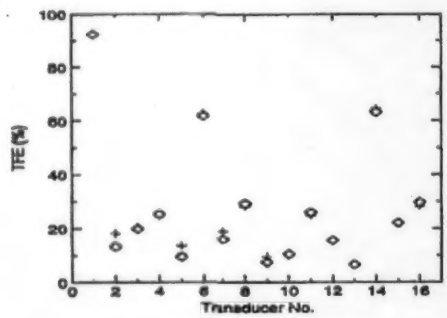
ITTC: Hs=3.26m, T=9.7s at Fn=0.0



JONSWAP: Hs=3.26m, T=9.7m at Fn=0.0

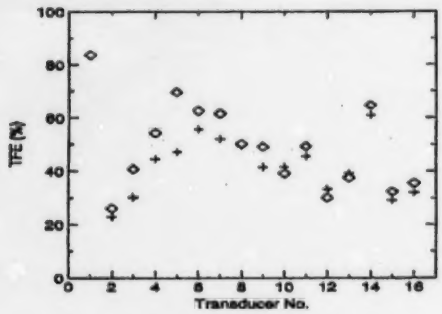


ITTC: Hs=5.0m, T=12.4s at Fn=0.0

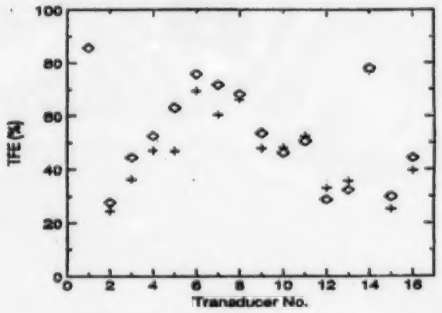


JONSWAP: Hs=5.0m, T=12.4m at Fn=0.0

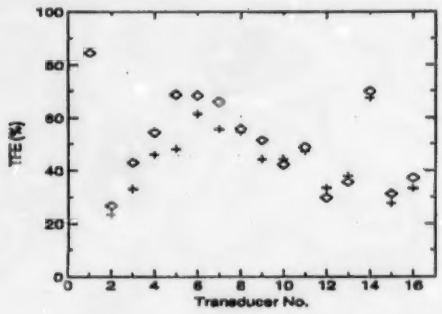
Figure 20. TFE's of pressures for WAVELOAD (◊) and PRECAL (+) for specified wave spectra and Froude numbers



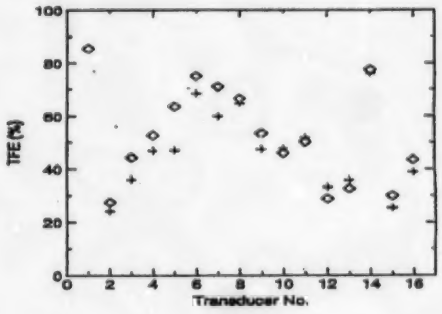
ITTC: Hs=1.88m, T=8.8s at Fn=0.1



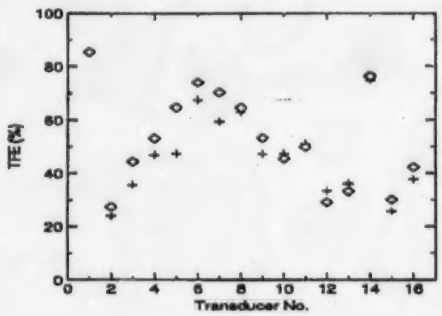
ITTC: Hs=7.5m, T=15s at Fn=0.1



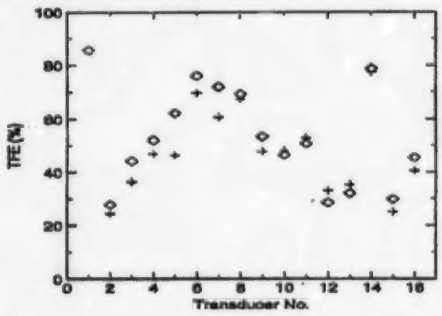
ITTC: Hs=3.26m, T=9.7s at Fn=0.0



JONSWAP: Hs=3.26m, T=9.7s at Fn=0.1

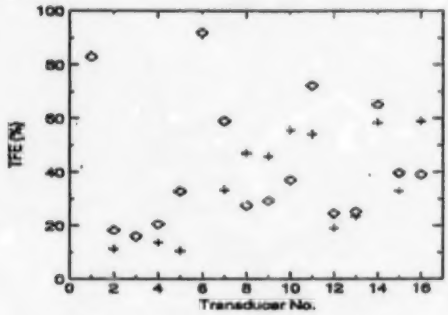


ITTC: Hs=5.0m, T=12.4s at Fn=0.1

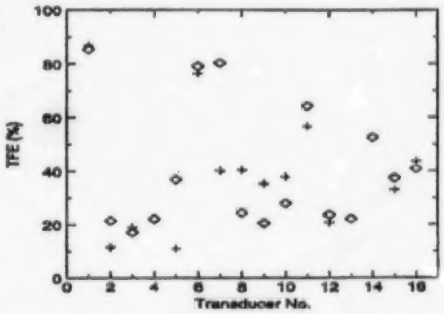


JONSWAP: Hs=5.0m, T=12.4s at Fn=0.1

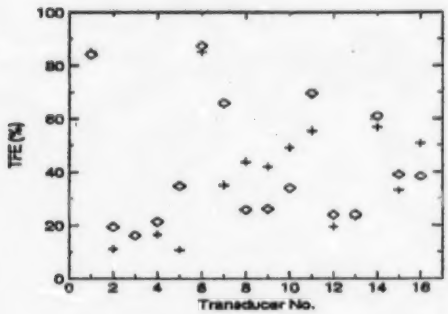
Figure 20. (Continued). TFE's of pressures for WAVELOAD (◊) and PRECAL (+) for specified wave spectra and Froude numbers



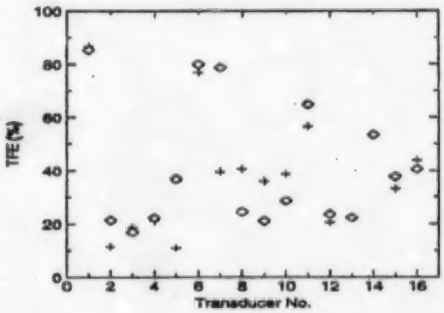
ITTC: Hs=1.88m, T=8.8m at Fn=0.2



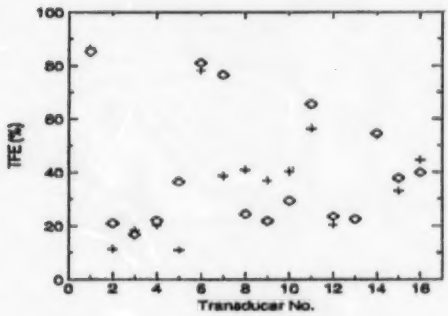
ITTC: Hs=7.5m, T=15.0s at Fn=0.2



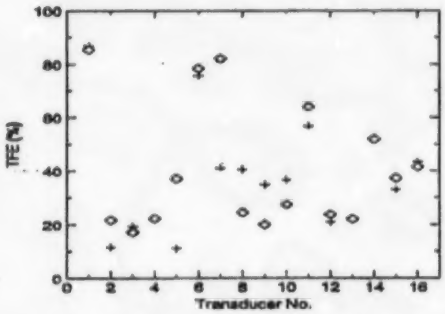
ITTC: Hs=3.26m, T=9.7s at Fn=0.2



JONSWAP: Hs=3.26m, T=9.7s at Fn=0.2

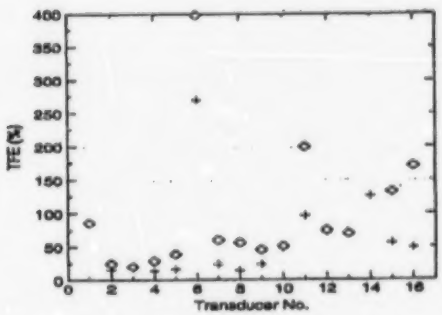


ITTC: Hs=5.0m, T=12.4s at Fn=0.2

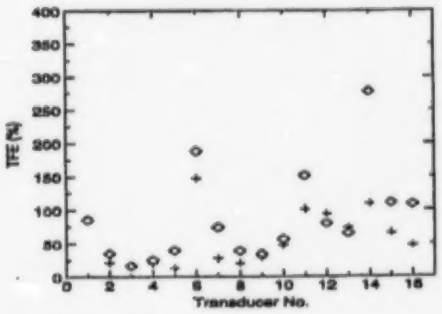


JONSWAP: Hs=5.0m, T=12.4s at Fn=0.2

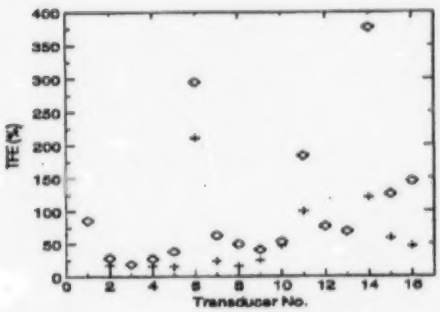
Figure 20. (Continued). TFE's of pressures for WAVELOAD (◊) and PRECAL (+) for specified wave spectra and Froude numbers



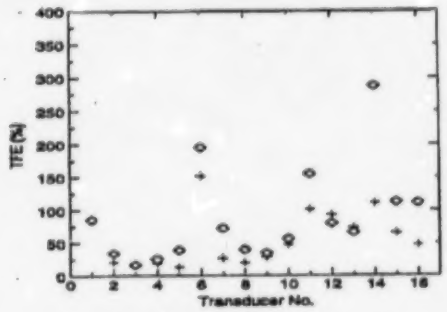
ITTC: Hs=1.88m, T=8.8s at Fn=0.29



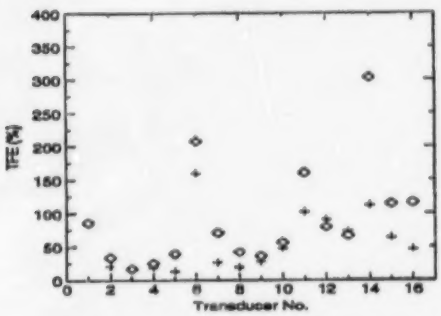
ITTC: Hs=7.5m, T=15.0s at Fn=0.29



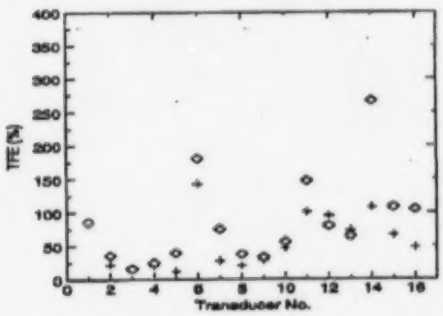
ITTC: Hs=3.26m, T=9.7s at Fn=0.29



JONSWAP: Hs=3.26m, T=9.7s at Fn=0.29

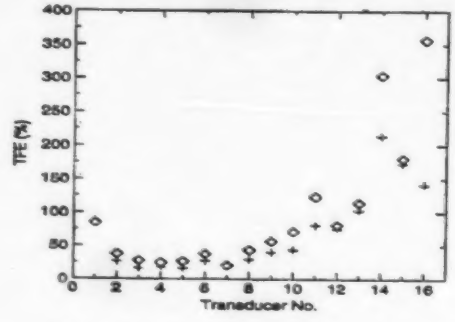


ITTC: Hs=5.0m, T=12.4s at Fn=0.29

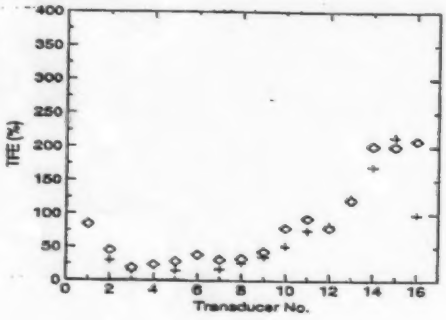


JONSWAP: Hs=5.0m, T=12.4s at Fn=0.29

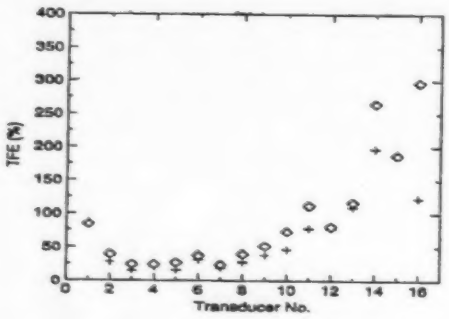
Figure 20. (Continued). TFE's of pressures for WAVELOAD (◊) and PRECAL (+) for specified wave spectra and Froude numbers



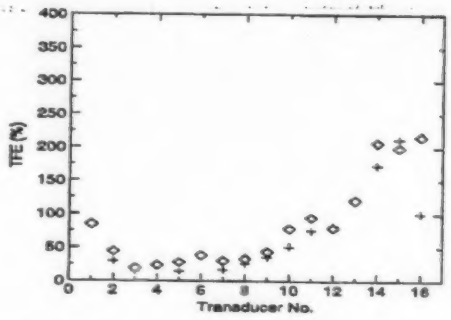
ITTC: Hs=1.88m, T=8.8s at Fn=0.37



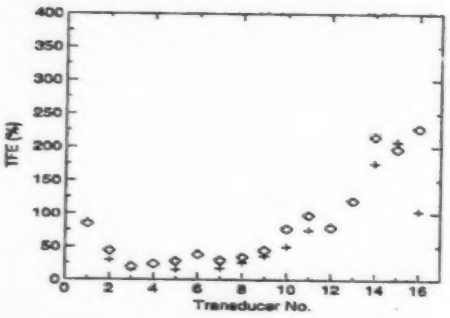
ITTC: Hs=7.5, T=15.0s at Fn=0.37



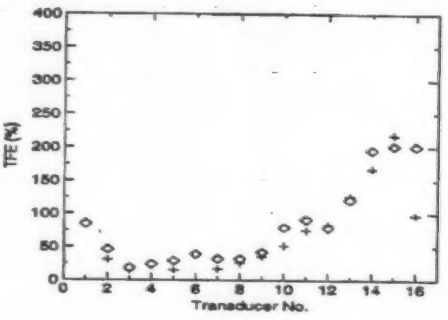
ITTC: Hs=3.26m, T=9.7s at Fn=0.37



JONSWAP: Hs=3.26m, T=9.7s at Fn=0.37

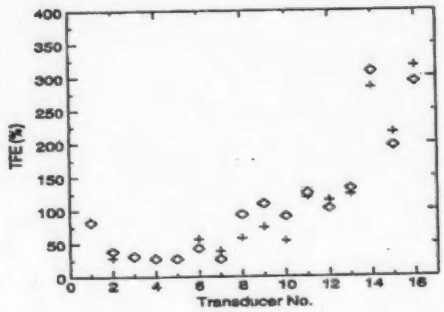


ITTC: Hs=5.0m, T=12.4s at Fn=0.37

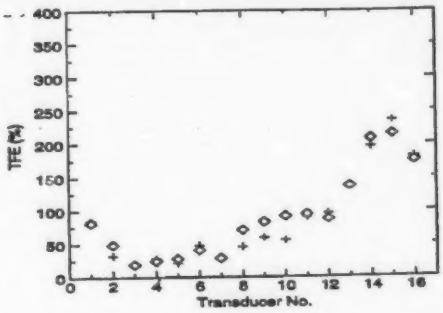


JONSWAP: Hs=5.0m, T=12.4s at Fn=0.37

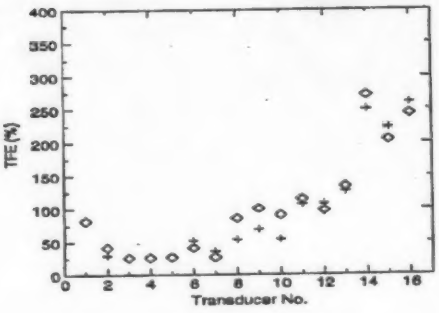
Figure 20. (Continued). TFE's of pressures for WAVELOAD (◊) and PRECAL (+) for specified wave spectra and Froude numbers



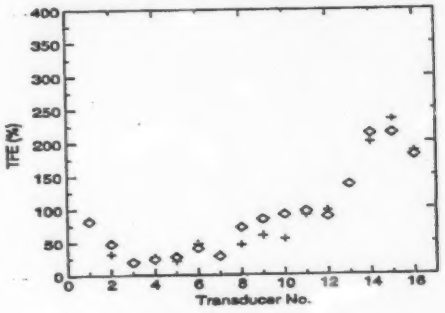
ITTC: Hs=1.88m, T=8.8s at Fn=0.39



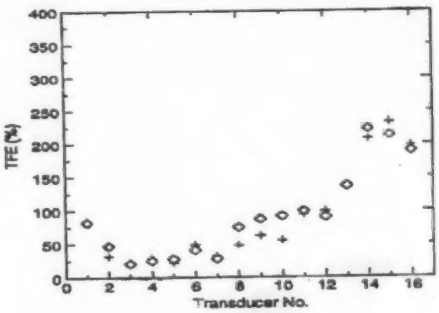
ITTC: Hs=7.5m, T=15.0s at Fn=0.39



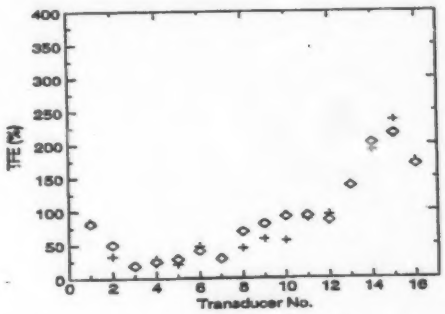
ITTC: Hs=3.26m, T=9.7s at Fn=0.39



JONSWAP: Hs=3.26m, T=9.7s at Fn=0.39



ITTC: Hs=5.0m, T=12.4s at Fn=0.39



JONSWAP: Hs=5.0m, T=12.4s at Fn=0.39

Figure 20. (Continued). TFE's of pressures for WAVELOAD (◊) and PRECAL (+) for specified wave spectra and Froude numbers

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The prediction of ship motions, sea loads and hydrodynamic pressure distribution over a ship hull is an essential component of ship structural design. The immediate goal is to provide accurate hull pressure input for the finite-element structural analysis. To this end, the computer program *WAVELOAD* version 1.0 has been developed to predict ship motions, wave loads, and hydrodynamic pressure in the frequency domain based on the three-dimensional panel method.

This report describes the experimental validation of this program using the data from experimental tests with a destroyer model in head seas. The total factor error (TFE) was used as an index of correlation of predicted and measured transfer functions. By examining TFE values, one can assess not only the degree of correlation between predicted and measured response transfer functions quantitatively, but also the reliability of the experimental data. The TFE analysis was applied to the predictions by two other computer programs, *PRECAL* and *SHIPMO7*, as well as to those by *WAVELOAD*. The results show that *WAVELOAD* is a reliable software package for sea-load predictions.

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